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Section 408
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Rural Electrification Administration
Telephone Engineering & Construction Manual

FACILITY REQUIREMENTS FOR VOICE FREQUENCY REPEATERED TRUNKS

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1. GENERAL

1.1 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It provides in particular technical information for use when making measurements required in REA Bulletin 383-2 "Acceptance Tests - Outside Plant" as part of the final acceptance testing of all trunk plant where application of voice frequency repeaters is contemplated.

1.2 The emphasis on obtaining and maintaining correctly loaded cables, free from the adverse effects of major impedance irregularities, is dictated by the increasing application of electronic gain to trunk plant such as afforded by the negative impedance on the hybrid (V-type) repeaters. If the design gains are to be realized without singing, hollowness or echo attention must be paid to the line regularity characteristics.

1.3 The performance of voice frequency repeaters depends not only on their design characteristics, but also on the electrical characteristics of the outside plant facilities over which they are to operate. Since voice frequency repeaters are purchased on a guaranteed performance basis from contractors other than those who construct the outside plant facilities, it is essential that facility loss or insertion loss measurements as applicable be made on the outside plant trunk facilities, prior to the installation of repeaters, to ensure their suitability for repeater application.

1.4 Facility loss measurements will enable the determination of any major impedance irregularities as well as the verification of the non-repeatered facility loss on which the repeater design is based. Correction of construction errors, if required, can then be made before installation of the repeaters and thus eliminate division of responsibility for repeater performance. REA Bulletin 383-2 "Acceptance Tests - Outside Plant" establishes these facility loss measurements as a requirement for Outside Plant Acceptance Testing where voice frequency repeaters are contemplated in trunk applications. It is the purpose of this section to describe the methods of making such measurements, to provide the basis for the interpretation of the results, and to furnish guide lines to follow in correcting any construction errors evidenced as a result of the measurements.

1.5 Specifically this section provides information on:

a. Where facility loss[1] or insertion loss[2] measurements as applicable, are made.

b. The method of measurement and the test equipment required.

c. Criteria for determining measured facility suitability to voice frequency repeater application.

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[1]Par. 4.1 defines "Facility Loss."
[2]Par. 4.4 defines "Insertion Loss."

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d. Attenuation and reflection loss information at 300, 500, 1000, 2000 and 3000 cps for the computation of the normal facility loss.

e. Location and correction of impedance irregularities.

1.6 This section considers both loaded cable and open wire measurements.

1.61 It deals primarily, however, with measurements of loaded cable circuits, since the bulk of the applications are expected to be on loaded repeatered trunks. The measurements made on loaded cable facilities are termed "facility loss" type of measurements.

1.62 Open wire measurements are treated in detail, however, in par. 8.4 and attenuation and reflection loss information given in Tables III and IV. The measurements made on open wire lines are termed "insertion loss" type of measurements.

1.63 Where no mention of the facility type is made in this section it should be assumed to refer to loaded cable.

2. THEORY OF IMPEDANCE IRREGULARITIES

2.1 Any condition that alters the impedance symmetry of a uniform line is classed an impedance irregularity. For example, the type of irregularities usually encountered in uniformly loaded cables are due to:

a. Omitted loading coils or those of incorrect inductance.
b. Loading sections of deficient or excess length.
c. Incorrect capacitance building our arrangements.

The most common source of impedance irregularities is due to omitted loading coils or the incorrect location of loading coils. Figure 1 illustrates types of loading irregularities. Only those cases where the d.c. continuity of the circuit is maintained are shown; there may be others such as opens in the pair, shorts, split pairs, etc.

2.2 Impedance irregularities produce reflection losses which result in:

a. An increase in the transmission loss and distortion of the circuit particularly at frequencies higher than 1000 cps.

b. A reduction in the structural return loss characteristics of the circuit.

2.3 Impedance irregularities whether due to excess or deficient inductance or capacitance will introduce reflections which increase the normal transmission loss of a circuit. The additional loss, with respect to normal, increases uniformly with frequency and is essentially independent of the location of the irregularities. Therefore, transmission loss measurements cannot be used to locate impedance irregularities but only to detect their presence. The increase in transmission loss is scarcely measurable at 1000 cycles but is easily noticeable at frequencies near 3000 cycles. Therefore, the method described in this section determines:

a. The 1000 cycle facility loss which may be used to compute the repeater gain.

b. Facility suitability necessary for repeatering.

c. Whether corrective measures are necessary to restore line regularity to normal.

2.4 The exact value of structural return loss which is used in conjunction with the 1000 cps loss for purposes of computing the repeater gain is at present arrived at independently and from consideration of the maximum limits on cable mutual capacitance deviation, the maximum allowable load spacing deviation and the maximum allowable loading coil inductance deviation as contained in applicable REA cable, loading coil specifications and sections of the manual and is given in REA TE & CM-444,"Calculation of Net Loss of Negative Impedance Repeatered, Loaded Trunks."

2.41 For exchange type cables manufactured under applicable REA specifications the values of structural return loss expected to be equalled or exceeded by 92% of the circuits at the critical frequency are:

19-H-88	16 db
22-H-88	19 db

2.5 Though not specifically directed to other than facility loss type of measurements, this section may be used in its broadest intent to provide the following additional operations:

a. To establish whether the actual performance of a contemplated system utilizing voice frequency repeaters meets design requirements.

b. To ascertain whether the gain of voice frequency repeaters operating over the given facilities, in a prescribed frequency range, is within design limits.

c. To provide for routine maintenance in accordance with present transmission practices, and adjustments as may be necessary so that satisfactory transmission of trunks under distance dialing can be maintained.

d. Trunk trouble-clearing can be performed on a coordinated basis to locate and correct the source of trouble. Compensating maladjustments must be avoided.

3. WHERE FACILITY LOSS MEASUREMENTS ARE MADE.

3.1 Facility loss measurements as described in this section are required in REA Bulletin 383-2 as part of the final acceptance testing of all EAS and toll connecting trunks where application of voice frequency repeaters is contemplated. These measurements are made as follows:

a. Where the offices between which the facility loss measurements are made are wholly contained within the borrowers boundary, these measurements are made for the entirety of the trunk route.

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b. Where the facilities will be used for tandem switching applications the facility loss measurements are made separately for each link.

c. Where voice frequency extensions of carrier or microwave derived trunks are involved, the facility loss measurements are made for the voice frequency facility portion only.

d. Where the facilities under consideration are joined at some intermediate point with a connecting company's facilities, the facility loss measurements should be made in their entirety and with the consent of the connecting company. Should this not be possible the measurements should be made at the boundary. (Connecting companies are usually agreeable to providing personnel for making these measurements if sufficient technical information is provided and definite arrangements for testing are made in advance.)

4. DEFINITIONS

4.1 Facility Loss. The term "Facility Loss" is used throughout this section to describe "Attenuation."

4.2 The general case of facility loss is defined as the loss resulting when the facility or network under measurement is terminated in its characteristic impedance.

4.21 Facility loss for the purpose of the measurements in this section is defined as the loss in db resulting from the insertion of a facility or network having 1000 ohm impedance between an 1000 ohm resistive source and a 1000 ohm resistive load. Further, for the measurements considered in this section the measuring oscillator and A-C VTVM equipment will be of the 600 ohm type, such as used for making insertion loss type of measurements, but externally modified through an impedance compensator to become 1000 ohm devices.

4.22 Facility Loss Measurements are made on loaded cables only.

4.3 Impedance Compensator. An impedance compensator for the purpose of the measurements described herein is defined as a device which modifies the facility impedance to 1000 ohms from 300 to 3000 cps and in addition modifies conventional 600 ohm measuring equipment to become suitable for 1000 ohm impedance measurements in the same frequency range.

4.31 The impedance matching properties of the impedance compensator are discussed in detail in par. 6.

4.4 Insertion Loss. The general case of insertion loss is defined as the loss resulting when the facility or network under test is NOT terminated in its characteristic impedance.

4.41 For the measurements considered in this section the source is always a 600 ohm oscillator and the load an A-C VTVM of high input impedance terminated in a 600 ohm $\pm$ 1%, 1 watt, carbon resistor.

4.42 Insertion loss measurements are made only for open wire lines.

4.5 DBM. The general case of 0 dbm is defined as 1 milliwatt power.

4.51 For the measurements considered herein 0 dbm is defined as the rms value of any single frequency tone corresponding to any of the following power levels:

a. 0.775 volts across a 600 ohm carbon resistor.

b. One milliwatt into a 600 ohm carbon resistor.

c. 1.29 milliamperes into a 600 ohm carbon resistor.

All power levels above 0 dbm are plus and all below minus. The relation between rms volts across 600 ohms and dbm levels is shown in Table I of REA TE & CM-407, Issue No. 1, "How to Make Insertion Loss Measurements."

5. RELATIONSHIP BETWEEN FACILITY LOSS AND INSERTION LOSS.

5.1 Insertion loss and facility loss are not the same; facility loss is a special case of insertion loss. The following principle should be helpful to clarify the difference:

To measure attenuation or facility loss only the facility under test must be terminated in its characteristic impedance. If a termination is used which is different than the facility characteristic impedance the resulting loss is attenuation plus reflection losses. Insertion loss is generally greater than attenuation or facility loss. The two are related as follows:

INSERTION LOSS = ATTENUATION + TERMINAL REFLECTIONS + INTERACTION

5.2 For loaded cables, the characteristic impedance as seen in Figure 6 and measured between one half end sections varies considerably from 300 to 3000 cps, in both magnitude and phase. If 600 ohm measuring equipment is used to measure a facility having such impedance characteristics, the measurement represents insertion loss since it includes not only attenuation but the resulting reflection losses between the facility and the measuring equipment. If, however, the facility had been measured with an oscillator and an A-C VTVM whose terminating impedance at each frequency under measurement were equal to the impedance of the line at the same frequency, the reflection loss and the interaction loss of the above expression would have been zero and the insertion loss would equal the attenuation or facility loss. Therefore, attenuation or facility loss can be thought of as the case of minimum insertion loss.

5.21 Depending on the magnitude and phase relationships of the impedances involved, it is possible to have negative reflections; this represents reflection gain.

5.22 Interaction losses are further extensions of reflection losses. They represent the sum total of all possible reflections traveling back and forth in the line as a result of impedance mismatches between the generator, facilities and load as modified by the attenuation of the line. The relation-

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ship which describes interaction losses is a highly complex one and unlike simple reflection loss is not readily adaptable to computation. For line losses greater than about 10 db, interaction may be safely ignored in insertion loss measurements.

5.3 In conclusion therefore it can be said that the main purpose of making facility loss type of measurements on loaded cable plant rather than insertion loss, with the aid of the impedance compensator, is to insure negligible terminal reflection effects due to mismatches between the 600 ohm test equipment and cable impedances at both ends of the line, to permit an accurate comparison between the computed and measured transmission losses and provide a basis for detecting the presence of impedance irregularities.

6. THE IMPEDANCE COMPENSATOR

6.1 As discussed previously the purpose of the impedance compensator is to minimize the effects of the terminal reflections due to mismatches between the 600 ohm test equipment at both cable ends and the dissimilar impedance of the cable pair under measurement. Specifically the purpose of the impedance matching network is threefold:

a. It builds the facility under test to 1000 ohms.

b. It builds the 600 ohm oscillator impedance to 1000 ohms.

c. It builds the 600 ohm A-C VTVM load resistance to 1000 ohms.

6.11 Such matched conditions minimize the terminal reflections and interaction losses as discussed in paragraph 5 above between the measuring equipment and the facility under test and result in attenuation only or facility loss. This method therefore permits an accurate comparison between the computed and measured facility loss in the range of 300 to 3000 cps.

6.2 The impedance matching network consists of three main sections as follows:

a. Cable build-out capacitor.

b. Inductor.

c. Measuring-equipment build-out resistor.

6.21 The purpose of the build-out capacitor is to build out each cable end section to approximately 4800', in order to obtain a resistance component of the cable impedance which is essentially constant over the frequency range.

6.22 The purpose of the inductor is to approximately cancel out the capacitive reactance of the cable impedance when built out to 4800' by the cable build-out capacitor, and thus produce an 1000 ohm resistance. The purpose of the equipment build-out resistor is to modify the 600 ohm equipment impedance to 1000 ohms. A facility thus modified is in accordance with the definition of par. 4.21.

6.3 Though the impedance matching network described above is readily available at low cost, it may nevertheless be constructed locally with the aid of radio parts and loading coils. A schematic diagram of the network, a list of component parts and method of connection is shown in attached Figure 5.

7. TEST EQUIPMENT REQUIRED

7.1 This paragraph summarizes the type and number of measuring equipment and accessories required according to the type of facility being measured and the method of measurement used. A list of instruments and accessories suitable for these measurements is also given.

7.2 Facility Loss Measurements - Loaded Cables

a. Impedance Compensator Method - Figure 2

One - Oscillator plus
Two - A-C VTVMS plus
Two - Impedance compensators plus
Two - Repeating Coils[1] plus
Two - 600 ohm resistors

b. Unequal Ratio Repeating Coil Method - Figure 3

One - Oscillator plus
Two - A-C VTVMS plus
Three - Repeating Coils (Western Electric Co. type 120 G) plus
Three - 600 ohm resistors

7.3 Insertion Loss Measurements - Open Wire Lines - Figure 4

One - Oscillator plus
Two - A-C VTVMS plus
Three - Repeating Coils (Western Electric Co. type 120 H) plus
Three - 600 ohm resistors

7.4 The following types of measuring equipment and accessories are suitable for making the transmission measurements described above.

7.41 Oscillator Equipment

a. Hewlett Packard Co. Type 200CD or equivalents listed below.
b. Western Electric Co. Type 19C.
c. Western Electric Co. Type 13A.
d. Western Electric Co. Type 21A.
e. Northeast Electronics Corp. Type TPS 4A.
f. Hallamore Electronics Co. Type TMS-0100.

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[1]Their use depending on whether an unbalanced to ground A-C VTVM is used. If a balanced Transmission Measuring Set is being used the repeating coils are not required.

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7.42 A-C VTVM Equipment

a. Hewlett Packard Co. Type 400D, H or L or equivalents listed below.
b. Western Electric Co. Type 13A.
c. Western Electric Co. Type 21A.
d. Northeast Electronics Corp. Type TPS 4A.
e. Hallamore Electronics Co. Type TMS-0100.

7.43 Repeating Coils

a. Western Electric Co. Type 120 H or equivalent. (For measurements of Figure 2 & 4).
b. Western Electric Co. Type 120 G or equivalent. (For measurements of Figure 3).

7.44 Impedance Compensators

a. Communication Engineering & Equipment Co. Type C-100 or equivalent.
b. Northeast Electronics Corp. Type TN-1 or equivalent.
c. Impedance compensator described in par. 6 and shown in Figure 5.

7.45 Resistors

600 ohms ± 1%, 1 watt carbon resistors.

8. PROCEDURE FOR CALIBRATION AND MEASUREMENT

8.1 This paragraph provides a step-by-step procedure for the calibration of the test equipment and the measurement of the facilities under test according to the type of facility and method used.

8.2 Facility Loss Measurements on Loaded Facilities - Impedance Compensator Method - Figure 2

8.21 Calibration of Test Equipment

a. Connect the oscillator, the 600 ohm resistor, the 120 H repeating coil and A-C VTVM as shown in Figure 2A. (Do not include the impedance compensator in the calibration setup)

b. Set the oscillator to a convenient frequency such as 2000 cycles.

c. Adjust the oscillator output level control to read +4.4 dbm on the A-C VTVM.

d. Do not change the oscillator output level. Vary the oscillator frequency from 300 to 3000 cps. The reading of the A-C VTVM should not change appreciably from that obtained in Step c. If varying the frequency changes the reading on the A-C VTVM by more than 0.2 db calibration at each frequency is required before measuring.

e. The calibration is now complete. Do not change the oscillator output level settings.

NOTE 1. The reason for a calibrating level of +4.4 dbm instead of the customary 0 dbm, is for calibrating-out the 4.4 db insertion loss due to the two 400 ohm resistors in the impedance compensators which are inserted in the circuit when making the facility loss measurements. This loss is independent of frequency. With the calibration made on this basis, the A-C VTVM reading upon measurement gives the facility loss directly.

NOTE 2. The 600 ohm resistor shown in Figures 2, 3, & 4 is not required if the transmission measuring set is being used. In addition the 120 H repeating coils shown in Figures 2 and 4 for balance purposes are not required if a Transmission Measuring Set is being used.

NOTE 3. Check the A-C VTVM before measurement. This may be conveniently accomplished by paralleling the two A-C VTVMS terminated in one 600 ohm resistor across the oscillator output terminals. In the frequency range of 300-3000 cycles the readings of the two units should be within 0.2 of a db of each other.

8.22 Measurement Procedure

a. The facility loss measurement is made on the line side of the office with the protector opened at the line contacts. (The central office equipment and associated wiring must not be included in the measurement).

b. Adjust the impedance compensator at each end to build out its respective end section to 4800 feet. (The physical length of each end section may not necessarily be the same.) Connect the impedance compensator to the measuring equipment as shown in Figure 2B, making sure the "Equipment Terminals" of the compensator are connected to the measuring equipment.

c. Insert the cable pair under test between the "Cable Terminals" of the impedance compensators as shown in Figure 2B.

d. Have personnel at the receiving end read the A-C VTVM. The reading in minus dbm (minus dbm from zero dbm) of the A-C VTVM at the oscillator frequency represents the loss in db of the facility at the same frequency.

e. Repeat the above procedure for the remainder of the frequencies under test. Measurements are made at the frequencies of 300, 500, 1000, 2000 and 3000 cps.

f. Enter the results of the measurements for each individual trunk according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

g. Record the facility loss of the line under test which has been previously computed and for the frequencies of par. e above and enter the results according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

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NOTE 1. Upon restoring cable pairs back into service by removing the toothpicks shreds of wood are often left in the contacts and cause trouble. Check for wood shreds or use highly polished very hard wood strip or a hard plastic strip which is the safest.

NOTE 2. It is important that the 3000 cps oscillator frequency be known accurately. Check the oscillator to be used with an oscillator of known frequency by the Lissajous or other calibration method and if necessary have the oscillator manufacturer calibrate the instrument.

NOTE 3. Where a large number of trunks in the same trunk group are measured it will be time-saving to arrange the trunks so that with the oscillator set at the same frequency all trunks can be measured in succession.

8.3 Facility Loss Measurements on Loaded Facilities - Unequal Ratio Repeating Coil Method - Figure 3.

8.31 Calibration of Test Equipment

a. Connect the oscillator, the 600 ohm resistor, the 120 G repeating coil and A-C VTVM as shown in Figure 3A.

b. Set the oscillator to the desired frequency and vary oscillator output level control to read 0 dbm on the A-C VTVM. (Calibration is required at each frequency).

c. Do not change oscillator output level.

8.32 Measurement Procedure

a. The facility loss measurement is made on the line side of the office with the protector opened at the line contacts. (The central office equipment and associated wiring must not be included in the measurement).

b. Insert the cable pair between the oscillator and the A-C VTVM as shown in Figure 3B.

c. With oscillator at the sending end set at the desired frequency and have personnel at the receiving end read the A-C VTVM.

d. The reading in minus dbm of the A-C VTVM at that frequency represents the loss in db of the facility at the same frequency and it includes reflection losses to the terminal equipment at the low and high frequencies.

e. Repeat the above procedure for the remainder of the frequencies under test. Measurements are made at the frequencies of 300, 500, 1000, 2000 and 3000 cps.

f. Enter the results of the measurements for each individual trunk according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

g. Record the facility loss of the line under test which has been previously computed and for the frequencies in paragraph e and enter the results according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

8.33 Note 3 of par. 8.21 and Notes 1 and 2 and 3 of par. 8.22 are also applicable.

8.4 "Insertion Loss" Measurements - Open Wire Lines

8.41 Calibration of Test Equipment

a. Connect the oscillator, the 600 ohm resistor, the 120 H repeating coil and A-C VTVM as shown in Figure 4A.

b. Set the oscillator to the desired frequency and vary oscillator output level control to read 0 dbm on the A-C VTVM. (Calibration is required at each frequency).

c. Do not change oscillator output level.

8.42 Measurement Procedure

a. The insertion loss measurement is made on the line side of the office with the protector opened at the line contacts. (The central office equipment and associated wiring must not be included in the measurement).

b. Insert the cable pair between the oscillator and the A-C VTVM as shown in Figure 4B.

c. With oscillator at the sending end set at the desired frequency and have personnel at the receiving end read the A-C VTVM.

d. The reading in minus dbm of the A-C VTVM at that frequency represents the loss in db of the facility at the same frequency and it includes reflection losses to the terminal equipment as well as the junction of dissimilar facilities.

e. Repeat the above procedure for the remainder of the frequencies under test. Measurements are made at the frequencies of 300, 500, 1000, 2000 and 3000 cps.

f. Enter the results of the measurements for each individual trunk according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

g. Record the insertion loss of the line under test which has been previously computed and for the frequencies in paragraph e and enter the results according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

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8.43 Note 3 of par. 8.21 and Notes 1 and 2 & 3 of par. 8.22 are also applicable.

9. INTERPRETATION OF FACILITY LOSS MEASUREMENTS

9.1 For purposes of clarification the concept of an "ideally loaded line" is useful. Such a line possesses the following characteristics:

a. The primary cable parameters at a given frequency have no deviations. (e.g. the distributed cable constants per unit length do not vary.)

b. The load spacing possesses no deviations. (All full sections are of exactly identical length).

c. The loading coil inductance possesses no deviations.

Under the above conditions the frequency-attenuation characteristics of such uniformly loaded cable would appear as a perfectly smooth and uniform curve and increasing up to the cutoff frequency.

9.2 In practice however the effect of random variations as described in Paragraph 9.21 below due to cable mutual capacitance deviations, load spacing deviations and loading coil inductance deviations present in uniformly loaded cables tend to introduce <u>minor</u> irregularities in an otherwise smooth frequency attenuation loss characteristic. Irregularities, however, which are the result of basic plant trouble such as for example shown in Figure 1 or misapplications are <u>major</u> and easily detectable by measurement. The degree of smoothness of the frequency loss characteristic of the facility measured provides an index as to whether the facility measured is suitable for voice frequency repeater applications or whether major faults exist which require remedial treatment.

9.21 Random variations are defined as those variations resulting from the aggregate effect of the deviations in the primary constants of cables due to manufacture with emphasis on the mutual capacitance deviation, the deviation in capacitance between loading sections due to loading coil spacing and deviations in loading coil inductance due to manufacture and all of which do not exceed the maximum limits contained in the appropriate REA cable or loading coil specifications or sections of the manual. Thus defined such random variations are considered normal.

9.3 A uniform facility possessing <u>no major irregularities</u> but <u>only random</u> variations is suitable for repeatering if:

9.31 The measured facility loss as compared to the calculated value obtained by multiplying the proper attenuation value (db/mi) in Table I by the facility length (mi) and corrected for temperature[1] is within:

± 10% at 1000 and 2000 cps and ± 20% at 300, 500, and 3000 cps for .083 ± 0.004 exchange type cables.

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[1]See REA TE & CM-407 "How to Make Insertion Loss Measurements" par. 7.05 and Example 8.

9.4 It is possible for the 1000 cps measured facility loss to depart from the value given in Table I and limits of paragraph 9.31 without adversely affecting the candidacy of such facility for voice frequency repeater application, assuming that no major irregularities are indicated at the test frequencies. Such a facility having a different 1000 cps facility loss than the applicable 1000 cps value given in Table I has no major irregularities but only random ones, and therefore is suitable for repeatering if:

9.41 The measured effective facility loss is within ± 20% of the measured 1000 cps facility loss.

9.411 The effective facility loss is arrived at by computing the arithmetic average of the measured facility loss at 300, 500, 1000, 2000 and 3000 cps.

Example:

A facility loss measurement of loaded cable yields the following data:

Frequency-cps	Facility Loss - db
300	7.4
500	9.1
1000	9.7
2000	10.3
3000	11.0
Total Facility Loss	47.5 db

The effective facility loss is 47.5/5 = 9.5 db. ANS. This particular example is also within the limits of par. 9.41.

9.42 For open wire lines

The measured effective facility loss does not exceed the measured 1000 cps loss by two db.

9.5 Trunks qualifying under paragraph 9.41 and 9.42 will have their repeater gain based on the measured 1000 cps loss.

10. ANALYSIS OF RESULTS FOR DETECTION OF IMPEDANCE IRREGULARITIES

10.1 If the measured facility does not qualify under paragraphs 9.3 and 9.4 then the following analysis must be made to determine the extent of the irregularity. The difference between the computed deviation and the measured deviation of the 1000 and 3000 cps loss is a direct criterion of the presence of impedance irregularities of the cable pair under test. In cables that are free from significant irregularities the measured deviation should not exceed the computed deviation by more than about one db. Differences greater than this indicate irregularities which require further investigation.

10.2 An estimation of the type of the impedance irregularity is sometimes possible from the measured and computed deviation. If for example the difference between the measured and computed deviations is 2 db then a 50%

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error in loading coil inductance may be suspected. If the difference is in the order of about 4.0 db an omitted, reversed or doubled up, loading coil may be suspected. Procedures are given in par. 11 below to facilitiate the location of such irregularities.

10.3 The computed deviation is arrived at as follows: Assume a 22 gauge H-88 loaded cable 6.5 miles in length.

a. The 1000 cps loss is 6.5 x 0.792 = 5.15 db
b. The 3000 cps loss is 6.5 x 1.05 = 6.83 db

The computed deviation is therefore 1.68 db

The measured deviation is arrived at as follows:

Assume the same 22 gauge H-88 loaded cable, as measured yields the following losses at 1000 and 3000 cps.

a. 1000 cps = 5.2 db
b. 3000 cps = 7.5 db

The measured deviation is therefore 2.3 db

The difference between the measured and computed deviation is:

2.3 - 1.68 = .62

Therefore the measured circuit is within the limits of 1 db and suitable for repeater use.

11. LOCATION OF IMPEDANCE IRREGULARITIES

11.1 Paragraph 10.2 establishes the extent of the impedance irregularities after measurements have been made. This part of the section describes various methods for determining the location of the impedance irregularities.

11.11 It is assumed that Wheatstone bridge measurements and other continuity tests required in REA Bulletin 383-2 have been made on all trunks prior to the facility loss measurements so that faults due to opens, shorts, crosses, grounds, split pairs, etc., may be excluded from the tests which follow. REA TE & CM-455, Addendum No. 2 provides information for use when making Wheatstone bridge measurements.

11.2 Method I. Visual Inspection

Method I is effective where splices to cable pairs at loading points are accessible. This will be possible for example for buried type cables where loading coils are installed at the pedestals and in aerial cable where ready access cases are used. In these cases such visual inspection will usually indicate omissions, reversals, damage as a result of lightning, incorrect value of inductance, etc. Loading coils however, which have been defective internally from the outset will not be detected by this method.

11.3 Method II. Short Circuit Method

11.31 For this type of measurement if a loading coil is being suspected of being the cause of the irregularity, a bridge such as the Western Electric Company's Type 1-B or equivalent which measures impedance, a variable frequency oscillator and an A-C VTVM are required. The same oscillator and A-C VTVM equipment used for the facility loss measurements are used. Measurements are made as follows:

a. The far-end of the cable is short-circuited.
b. Measure the inductive reactance of the cable pair, (X_L), at 200 cps and from this value determine the inductance of the circuit by means of the formula:

$$\left[\ L = 0.8X_L\ \right] \qquad \text{in millihenries}$$

Where X_L is the measured inductive reactance in ohms.

c. Compute the correct inductance of the cable pair by multiplying the number of loading points to the short circuit times the nominal inductance of the loading coils. Compare this value with the measured inductance as found in Step b.

d. Any pronounced difference between the measured and computed inductance is a direct measure of the correctness of loading regularity. An omitted loading coil or a doubled-up loading coil is particularly noticeable with this method.

Example: Assume an H-88 loaded line under test contains four loading points and under the short circuit measurement the bridge yields 330 reactive ohms, at 200 cps.

a. The total measured inductance is:

$L = 0.8 \times 330 = 264$ millihenries.

b. The computed inductance is:

$88 \times 4 = 352$ millihenries.

The difference between the measured and computed inductance is:

$264 - 352 = -88$ millihenries, and therefore, indicative of a missing loading coil.

Note: The cable pair inductance of approximately one millihenry per mile should properly have been added to the coil inductance for computation. Since however random variations in the loading coil inductance are of the same order of magnitude such accuracy for the purposes of these measurements is not warranted.

This method yields valid results up to about 4 loading sections since the resistance of the cable pair for longer lengths tends to introduce an appreciable error. For lines containing a greater number of loading points sectionalization is necessary.

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11.4 Method III. Peak and Valley Method

11.41 This method utilizes the same test equipment as Method II above but in addition it requires a precision balancing network to terminate the line at the far-end. For 22 and 19 gauge exchange type cables H-88 loaded, this network is usually a Western Electric Company type 115 H or equivalent; the Western Electric Co. 115AL network applies to 24 gauge H-88 loaded cables. The Ceeco Co. C-100 impedance compensator, which is used for making the transmission loss measurements outlined above, also contains a precision balancing network, and can be strapped to accommodate 19 and 22 gauge H-88 loaded, exchange type cables.

11.42 According to this method when the distant end of the line is terminated in a precision balancing network a major impedance irregularity reflects a corresponding portion of the transmitted signal to the sending end. If this measurement is carried over a number of frequencies and the impedance plotted, a number of peaks and valleys will result (maximum and minimum points). Figure 6 shows the midsection impedance of 19 and 22 gauge H-88 loaded cables free of any impedance irregularities, for comparison.

11.43 The distance to the irregularity is found by noting the two consecutive peaks of the resistance component of the impedance plot and the respective frequencies at which they occur. The formula used is:

$$D = \frac{5000}{f2-f1}$$

Where D is the distance in miles to the fault and f2 and f1 are frequencies in cycles per second at which consecutive peaks occur. (Frequency f2 is greater than f1).

The above method yields valid results where only one major irregularity exists.

11.5 Method IV. - Using the Ceeco Co. C-100 Test Set

11.51 This method uses the same type of test equipment as that required to make the facility insertion loss measurements. In addition it requires a Western Electric Co. type 12B transmission measuring set or a Triplett type 630-NA or a Simpson type 260 VOM or equivalent.

11.52 Method IV is essentially identical in principle to Method III; it does not, however, require the use of an impedance bridge, neither does it require calculations. It is simple to use and relatively rapid. Good results can be obtained up to 6 loading points. Lines containing a greater number than this should be sectionalized.

11.53 The Ceeco Co. C-100 Test Set or equivalent may be used for fault location. The instruction manual provided by the manufacturer in connection with its C-100 test set provides an adequate test procedure. The manufacturers suggested procedure should therefore be followed.

12. ATTENUATION DATA & OTHER INFORMATION

12.1 Attenuation information is given in this section so that the results of the facility losses as measured at each frequency may be checked. Table I provides attenuation information at 300, 500, 1000, 2000 and 3000 cps for the following facilities.

a. 24, 22 and 19 gauge H-88 loaded exchange type cable, having 0.083 ± 0.004 microfarads per mile mutual capacitance.

b. 19 gauge H-88 loaded toll grade cable of 0.066 microfarads per mile mutual capacitance.

12.2 Tables II & III provide attenuation information at 300, 500, 1000, 2000 and 3000 cps for the following facilities.

a. 19, 22 and 24 gauge non-loaded exchange type cables having 0.083 ± 0.004 microfarad per mile mutual capacitance and 19 gauge toll grade 0.066 microfarad per mile.

b. .080"-30% and .104"-40% C-S open wire conductors.

c. .109"-135 steel open wire conductors.

12.3 Reflection losses between 24, 22 and 19 gauge exchange type cables H-88 loaded from 300 to 3000 cps are negligible; they may be considered to be zero for computation purposes. Table IV provides reflection losses for various dissimilar non-loaded cables and open wire lines.

13. SUPPLEMENTARY TECHNICAL INFORMATION REQUIRED

13.1 For each trunk group measured, and in addition to the results of the transmission measurements outlined above the following additional information should be assembled in a form similar to the attached Exhibit 1 - Data Record - Voice Frequency Transmission Measurements. This information is required for inclusion into REA Form 397-a "Performance Requirements - Voice Frequency Repeatered Trunks" in order to enable the repeater suppliers to correctly engineer and in addition guarantee the in-plant performance of their electronic equipment.

1. The location of all central offices or other structures in which repeaters are to be housed.

2. Overall facility length, including all lengths of dissimilar sections making up trunk route. This may be conveniently shown as a simple line schematic.

3. Capacitance of all cables making up trunk route and length of each and denoted as new, existing, polyethylene, paper, etc. This may be conveniently shown as an applicable REA PE Specification, or other applicable specification.

4. Gauge of all cables making up trunk route and length of each.

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5. Weight of loading and manufacturers type of loading coil(s). The latter may be conveniently shown as the applicable REA specification.

6. The average load spacing and the deviations of load spacing of the entire as-built, trunk route, as follows.

   a. The as-built deviation of average spacing from the standard system spacing in feet.

   b. The as-built deviation of any individual loading section from the average spacing in feet.

   c. The as-built arithmetic deviation of all loading sections.

   d. The as-built length of each loading section including external building out if any.

7. The as-built length of the end sections, including external building out, if any as it applies to each office end section as well as intermediate end sections (where intermediate repeaters are involved). If building out is to be performed in the repeater, a note to this effect will suffice.

8. Where open wire is involved the following additional information should be shown: Type and approximate age of conductor, conductor spacing, transposition system, approximate average pole spacing. In addition the manufacturer and type of all carrier line treatment networks on trunks to be repeatered. Also signaling arrangements where carrier channels with voice frequency extensions are used.

9. D.C. loop resistance and resistance unbalance measured as per REA TE & CM-455, Addendum No. 2 and outside temperature and weather conditions during measurements.

10. Type of signaling terminations.

11. Manufacturer and type of existing or proposed central office equipment.

12. Where the information is available, items 1 to 10 as they apply to the connecting company's portion.

13. Type of service rendered by these trunks and their transmission objectives in db at 1000 cps.

14. ILLUSTRATIVE EXAMPLES

Illustrative Example 1. Facility loss measurements were made on three circuits consisting of 7.28 miles of 22-H-88 loaded cable. The temperature was 70°F. The measuring equipment was calibrated as per Figure 2A and the facilities measured as per Figure 2B. The results for the three cable pairs measured are tabulated in par. 2 below.

1. Computation of Normal Loss (Par. 8.22-g)

Frequency-cps	Facility Loss - db
300	0.703 x 7.28 = 5.12
500	0.776 x 7.28 = 5.65
1000	0.792 x 7.28 = 5.77
2000	0.837 x 7.28 = 6.09
3000	1.05 x 7.28 = 7.64

2. Results of Measurements (Par. 8.22-f)

Frequency-cps	Measured Facility Loss-db			Computed Facility Loss-db
	Pair No. 1	Pair No. 2	Pair No. 3	
300	4.9	5.0	4.9	5.12
500	5.4	5.5	5.5	5.65
1000	5.8	5.9	5.8	5.77
2000	5.9	6.0	6.0	6.09
3000	6.5	6.6	6.4	7.64

3. Computation of Variation - Pair No. 1

Frequency-cps	Percent Variation
300	(5.12 - 4.9)/5.12 = 4.3
500	(5.65 - 5.4)/5.65 = 4.4
1000	(5.77 - 5.8)/5.77 = -0.5
2000	(6.09 - 5.9)/6.09 = 3.1
3000	(7.64 - 6.5)/7.64 = 14.9

The same procedure is repeated for Pair Nos. 2 and 3. The results are shown below:

4. Variation of Measured Facility Loss from Computed in Percent

Frequency-cps	Pair No. 1	Pair No. 2	Pair No. 3
300	4.3	2.3	4.3
500	4.4	2.7	2.7
1000	-0.5	-2.3	-0.5
2000	3.1	1.5	1.5
3000	14.9	13.6	16.5

5. Analysis of Results. The variation of the measured facility loss shown in par. 4 above shows the measured cable pairs to be within the limits of ± 10% at 1000 and 2000 cps and ± 20% at 300, 500 and 3000 cps as established in par. 9.31. The measured cable pairs are therefore suitable for repeater application. Further computations for conformance to par. 9.41 are not required.

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Illustrative Example 2. The results of facility loss measurements on 14.4 miles of 22-H-88 loaded cable made at 72°F. are shown below. The computation of the normal facility loss shown in Column six, was made in advance following the procedure of Example 1.

1. Results of Measurements

Frequency cps	Measured facility loss in db Trunk #1	Trunk #2	Trunk #3	Trunk #4	Computed-db
300	7.4	7.6	7.7	7.5	10.1
500	9.1	9.4	9.4	9.1	11.2
1000	9.7	9.7	9.6	9.8	11.4
2000	10.3	10.0	10.3	10.3	12.1
3000	11.0	11.3	11.0	11.3	15.1

2. Computation of Variation in Percent for Conformance to par. 9.31

Frequency-cps	Trunk No. 1	Trunk No. 2	Trunk No. 3	Trunk No. 4
300	-26.7	-24.8	-23.8	-25.7
500	-18.8	-16.1	-16.1	-18.8
1000	-14.9	-14.9	-15.8	-14.0
2000	-14.9	-17.4	-14.9	-14.9
3000	-27.2	-25.2	-27.2	-25.2

It is evident from an inspection of the above variations that the above trunks do not meet the requirements of par. 9.31. They will however be suitable for repeater application if they meet the effective loss requirements of par. 9.41. This is next shown below:

3. Computation of Effective Facility Loss for Conformance to par. 9.41

Trunk No.	Measured 1000 cps Loss-db	Measured Effective Loss-db	Difference db-Percent	
1	9.7	9.5	0.2	2.1
2	9.7	9.6	0.1	1.0
3	9.6	9.6	0	0
4	9.8	9.6	0.2	2.0

4. Analysis of Results. Inspection of Column four reveals the measured trunks to be well within the ± 20 percent requirement of par. 9.41. These trunks are suitable for repeater application.

Illustrative Example 3. Facility loss measurements were made on 6.8 miles of 19-H-88 cable at 68°F. The results of the measurements and the computations are shown below.

Frequency-cps	Measured Facility Loss-db	Computed-db
300	3.5	2.55
500	3.5	2.78
1000	3.5	2.88
2000	5.0	3.02
3000	12.5	3.85

Cursory comparison of the measured and computed results shows that the limits of paragraph 9.31 are greatly exceeded. The exact amount is shown below:

Variation of Measured Facility Loss from Computed - Percent.

Frequency-cps	Variation
300	37
500	26
1000	22
2000	66
3000	225

Notice the big percent variation between 1000 and 3000 cps. This is indicative of major irregularities. The measured effective facility loss is computed next, as previously described.

Measured Effective Facility Loss	:	5.6 db
Measured 1000 cps Facility Loss	:	3.5 db
Difference		2.1 db or 60.0 percent

The limits of paragraph 9.41 are exceeded also.

Analysis. The above results indicate major line irregularity; this is probably due to a missing loading coil.
The facility as measured is unsuitable for application of voice repeaters until the irregularity has been corrected.

Procedure: Apply paragraph 11 to locate the irregularity. Correct such irregularities before installation of voice frequency repeaters.

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Illustrative Example 4. (Exchange Type Loaded Cables of Mixed Gauges)

Facility loss measurements were made on 13.68 miles of mixed-gauge H-88 loaded buried cable. The facility-makeup was as follows: 0.25 miles 24 gauge, 5.87 miles 22 gauge and 7.56 miles 19 gauge. The results of the measurements are tabulated in par. 1 below. Ground temperature (in the shade and at cable depth) was approximately 53°F.

1. Computation of Normal Loss

The attenuation values of Table I for 55°F are used.

300 cps	0.25 mi.	24-H-88 x 0.974 db per mi.	= 0.24 db
	5.87 mi.	22-H-88 x 0.685 db per mi.	= 4.02 "
	7.56 mi.	19-H-88 x 0.365 db per mi.	= 2.76 "
		Total Facility Loss	7.02 db

Frequency cps	Computed Facility Loss-db	Measured Facility Loss-db	Percent Variation
300	7.02	6.6	6.0
500	7.73	7.6	1.7
1000	7.95	8.2	-3.1
2000	8.36	8.4	-0.5
3000	10.56	11.4	-7.9

2. Analysis of Results. The above trunk is within the requirements of par. 9.31 and therefore suitable for repeater application.

TABLE I

FREQUENCY - ATTENUATION CHARACTERISTICS IN DB PER MILE
PLASTIC INSULATED H-88 LOADED CABLES AT 55[1] AND 68°F.[2]

Frequency CPS	0.083 μf per mile (Note 3)						0.066 μf/Mi	
	24-H-88		22-H-88		19-H-88		19-H-88	
	55°F	68°F	55°F	68°F	55°F	68°F	55°F	68°F
300	0.974	1.00	0.685	0.703	0.365	0.375	0.341	0.350
500	1.10	1.13	0.756	0.776	0.398	0.409	0.365	0.375
1000	1.19	1.22	0.771	0.792	0.412	0.423	0.376	0.386
2000	1.27	1.30	0.815	0.837	0.431	0.443	0.424	0.436
3000	1.61	1.65	1.02	1.05	0.551	0.566	0.431	0.443

TABLE II

FREQUENCY - ATTENUATION CHARACTERISTICS IN DB PER MILE
PLASTIC INSULATED NON-LOADED CABLES AT 68°F. (NOTE 4)

Frequency -cps-	0.083 μf Per Mile (Note 3)			0.066 μf per mile
	24 GA.	22 GA.	19 GA.	19 GA.
300	1.27	1.00	0.707	0.625
500	1.64	1.29	0.908	0.801
1000	2.31	1.83	1.27	1.11
2000	3.23	2.55	1.74	1.52
3000	3.94	3.10	2.08	1.80

TABLE III

FREQUENCY - ATTENUATION CHARACTERISTICS IN DB PER MILE
OPEN WIRE CONDUCTORS AT 68°F.[4] - DRY WEATHER[5]
WIRE SPACING AS NOTED

Frequency - cps -	(Note 6)				(Note 7)
	.080"-30% C-S		.104"-40 C-S		.109"-135 Steel
	8"	12"	8"	12"	Class A-12"
300	0.16	0.15	0.11	0.10	0.18
500	0.21	0.20	0.14	0.13	0.25
1000	0.28	0.25	0.16	0.15	0.31
2000	0.32	0.30	0.18	0.16	0.41
3000	0.34	0.32	0.19	0.17	0.53

Notes:

1. Use for temperatures between 50 to 60°F. and where results of measurements do not warrant closer accuracy. Where required, correct at exact temperature via formula in REA TE & CM-407 par. 7.05 and Example 8.
2. Use for temperatures between 60 to 75°F. and where results of measurements do not warrant closer accuracy. Where required, correct at exact temperature via formula in REA TE & CM-407 par. 7.05 and Example 8.
3. Assumes 0.083 ± 0.004 microfarad per mile cables conforming to applicable REA specifications. Loading coils conform to applicable REA Specifications for 88 mh Loading Coils.
4. Temperature corrections for other than 68°F. are given in REA TE & CM-407, Issue No. 1, par. 7.05 and Example 8.
5. For wet weather, refer to REA TE & CM-406, Issue No. 2.
6. Assumes 25.5 pairs of #17 insulators per mile.
7. Assumes 9 pairs of DP insulators and 9 pairs of TW insulators per mile.

TABLE IV. REFLECTION LOSSES IN DB AT VARIOUS FREQUENCIES - NON-LOADED CABLES AND OPEN WIRE LINES

Facility	24 NL	22 NL	19 NL	.104-40%	.080"-30%	.109"-135	600 Ω
24 NL	--	0.1	0.4	0	0.1	0.3	0
22 NL		--	0.2	0.1	0.2	0.5	-0.4
19 NL			--	0.4	0.7	1.2	-0.6
.104"-40% C-S				--	0.1	0.3	0.1
.080"-30% C-S					--	0.1	0.7
.109"-135 Steel	300 CPS					--	1.4
600 Ω							--

Facility	24 NL	22 NL	19 NL	.104-40%	.080"-30%	.109"-135	600 Ω
24 NL	--	0.1	0.4	-0.1	0.1	0.3	-0.3
22 NL		--	0.2	0	0.2	0.6	-0.6
19 NL			--	0.3	0.6	1.4	-0.6
.104"-40% C-S				--	0.1	0.4	0
.080"-30% C-S					--	0.1	0.2
.109"-135 Steel	500 CPS					--	1.0
600 Ω							--

Facility	24 NL	22 NL	19 NL	.104-40%	.080"-30%	.109"-135	600 Ω
24 NL	--	0.1	0.5	-0.2	0	0.4	-0.6
22 NL		--	0.1	0	0.2	0.8	-0.6
19 NL			--	0.4	0.5	0.9	-0.4
.104"-40% C-S				--	0.2	0.4	-0.1
.080"-30% C-S					--	0.2	0.1
.109"-135 Steel	1000 CPS					--	0.7
600 Ω							--

Facility	24 NL	22 NL	19 NL	.104-40%	.080"-30%	.109"-135	600 Ω
24 NL	--	0.1	0.4	-0.2	0	0.8	-0.6
22 NL		--	0.2	0	0.3	1.2	-0.4
19 NL			--	0.5	0.8	2.1	0
.104"-40% C-S				--	0	0.4	-0.1
.080"-30% C-S					--	0.3	-0.1
.109"-135 Steel	2000 CPS					--	0.4
600 Ω							--

Facility	24 NL	22 NL	19 NL	.104-40%	.080"-30%	.109"-135	600 Ω
24 NL	--	0.1	0.4	-0.2	0.1	0.9	-0.6
22 NL		--	0.2	0.2	0.3	1.4	-0.3
19 NL			--	0.8	1.1	2.3	0.4
.104"-40% C-S				--	0	0.4	0
.080"-30% C-S					--	0.2	0
.109"-135 Steel	3000 CPS					--	0.2
600 Ω							--

EXHIBIT 1. DATA RECORD — VOICE FREQUENCY TRANSMISSION MEASUREMENTS

DATE OF MEASUREMENTS: _____

OFFICE _____ TO OFFICE _____

WEATHER & OUTSIDE TEMP: _____

TRANSMISSION OBJECTIVES IN DB _____

	TRUNK NO.	PAIR NO. OFFICE A	PAIR NO. OFFICE B	RDC LOOP OHMS	R. UNBAL. OHMS	LOSS IN DB AT FREQUENCIES INDICATED BELOW — CPS 300	500	1000	2000	3000	
											← COMPUTED
1											MEASURED ↓
2											
1											
2											
1											
2											
1											
2											
1											
2											
1											
2											

NOTES: SPACE 2 OF THIS SUGGESTED FORM MAY ALSO BE USED FOR RECORDING NET CIRCUIT LOSS OR REPEATER GAIN IF DESIRED.

— USE DIFFERENT SHEET FOR DIFFERENT TRUNK GROUP.

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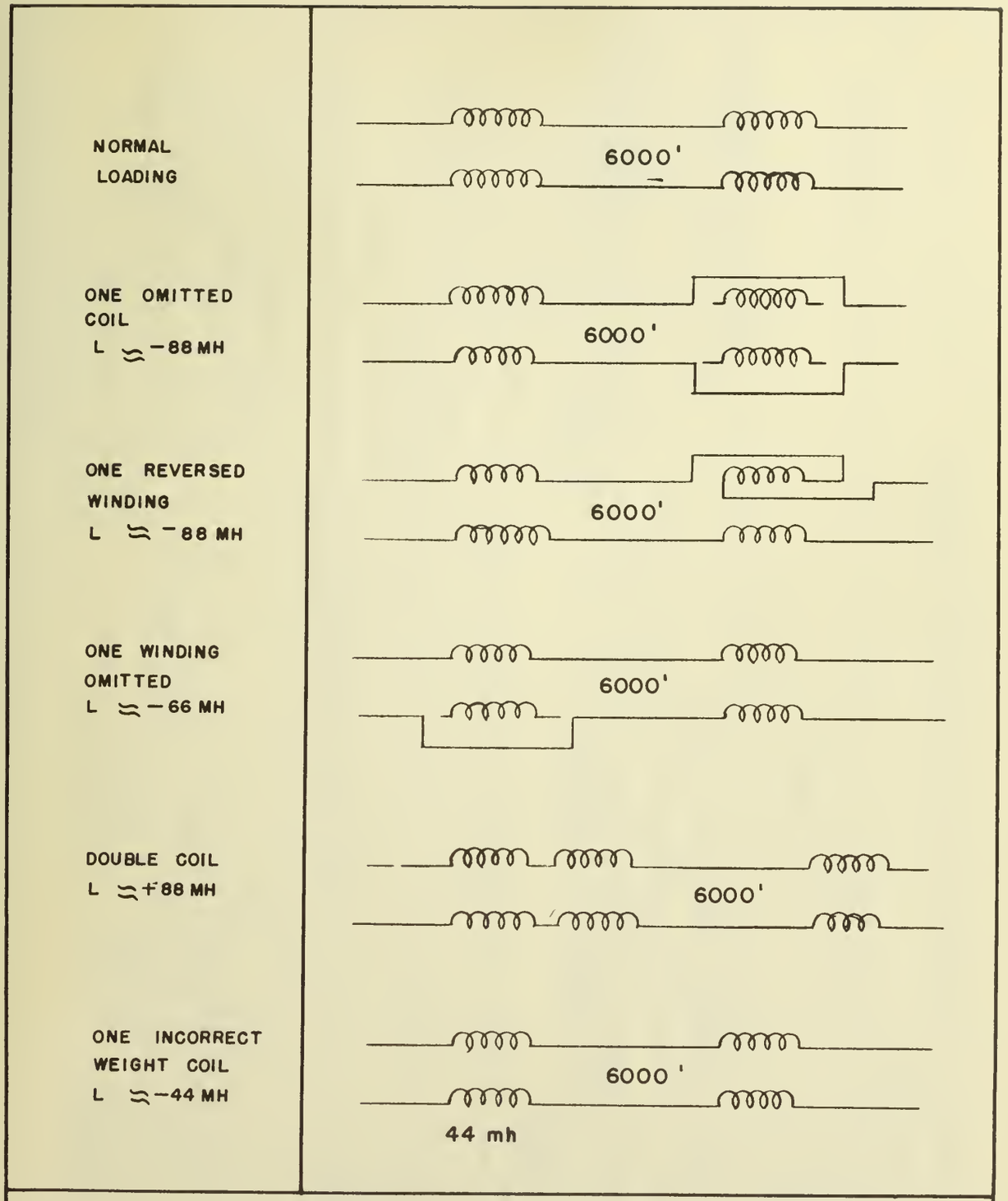


FIGURE 1
TYPE OF LOADING IRREGULARITIES
FOR H-88 LOADING

PROCEDURE FOR CALIBRATION AND MEASUREMENT (THIS IS PAR. 8.2 REPEATED HERE FOR CONVENIENCE)

Calibration of Test Equipment

a. Connect the oscillator, the 600 ohm resistor, the 120 H repeating coil and A-C VTVM as shown in Figure 2A. (Do not include the impedance compensator in the calibration setup)

b. Set the oscillator to a convenient frequency such as 2000 cycles.

c. Adjust the oscillator output level control to read +4.4 dbm on the A-C VTVM.

d. Do not change the oscillator output level. Vary the oscillator frequency from 300 to 3000 cps. The reading of the A-C VTVM should not change appreciably from that obtained in Step c. If varying the frequency changes the reading on the A-C VTVM by more than 0.2 db calibration at each frequency is required before measuring.

e. The calibration is now complete. Do not change the oscillator output level settings.

NOTE 3. Check the A-C VTVM before measurement. This may be conveniently accomplished by paralleling the two A-C VTVMS terminated in one 600 ohm resistor across the oscillator output terminals. In the frequency range of 300-3000 cycles the readings of the two A-C VTVMS should be within 0.2 of a db of each other. (See par. 8.21 for Notes 1 and 2).

Measurement Procedure

a. The facility loss measurement is made on the line side of the office with the protector opened at the line contacts. (The central office equipment and associated wiring must not be included in the measurement).

b. Adjust the impedance compensator at each end to build out its respective end section to 4800 feet. (The physical length of each end section may not necessarily be the same.) Connect the impedance compensator to the measuring equipment as shown in Figure 2B, making sure the "Equipment Terminals" of the compensator are connected to the measuring equipment.

c. Insert the cable pair under test between the "Cable Terminals" of the impedance compensators as shown in Figure 2B.

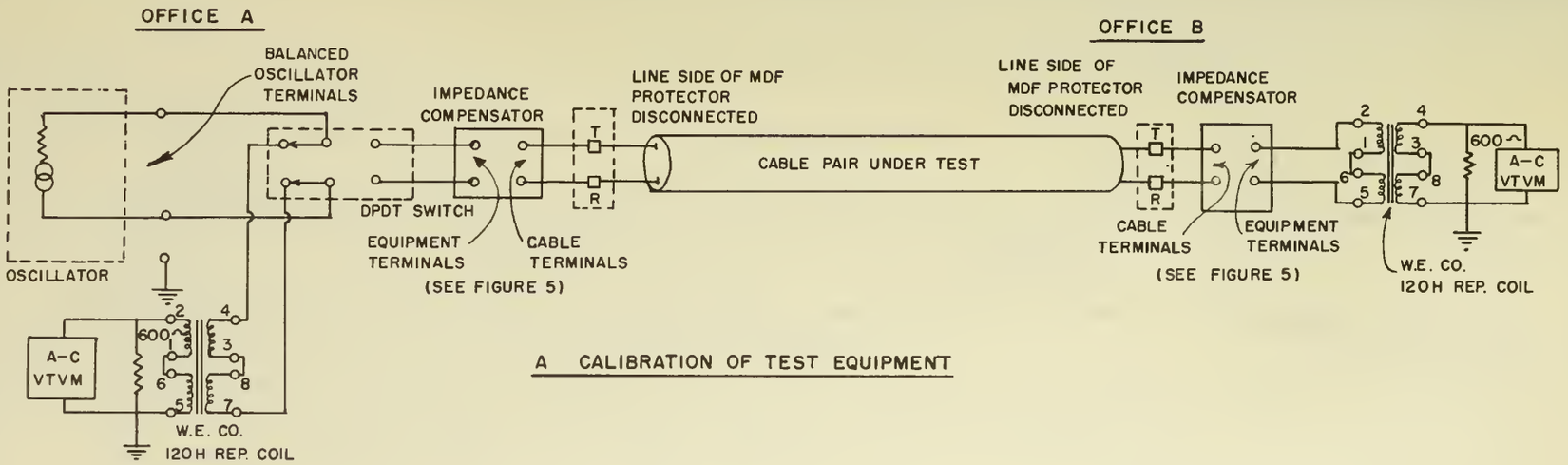
d. Have personnel at the receiving end read the A-C VTVM. The reading in minus dbm (minus dbm from zero dbm) of the A-C VTVM at the oscillator frequency represents the loss in db of the facility at the same frequency.

e. Repeat the above procedure for the remainder of the frequencies under test. Measurements are made at the frequencies of 300, 500 1000, 2000 and 3000 cps.

f. Enter the results of the measurements for each individual trunk according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

g. Record the facility loss of the line under test which has been previously computed and for the frequency in par. e above and enter the results according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

NOTE 2. It is important that the 3000 cps oscillator frequency be known accurately. Check oscillator to be used as per procedure of NOTE 2, par. 8.22. (See par. 8.22 for Notes 1 and 3).



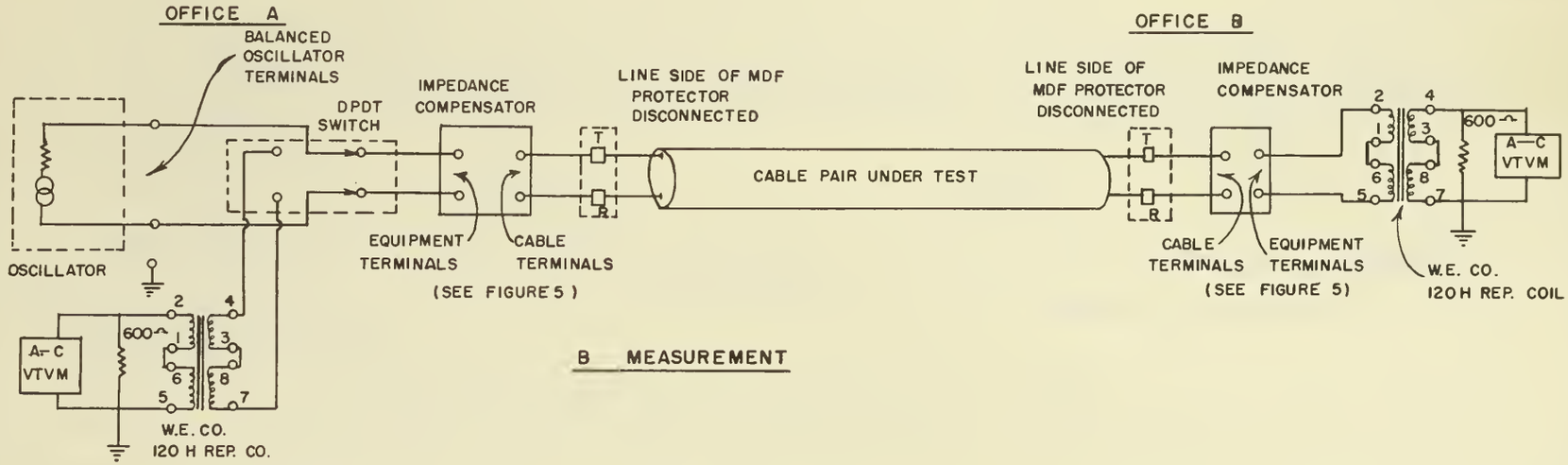


FIGURE 2 CALIBRATION AND MEASUREMENT OF LOADED CABLE FACILITY LOSS USING THE IMPEDANCE COMPENSATOR

PROCEDURE FOR CALIBRATION & MEASUREMENT (THIS IS PAR. 8.3 REPEATED HERE FOR CONVENIENCE)

Calibration of Test Equipment

a. Connect the oscillator, the 600 ohm resistor, the 120 G repeating coil and A-C VTVM as shown in Figure 3A.

b. Set the oscillator to the desired frequency and vary oscillator output level control to read 0 dbm on the A-C VTVM. (Calibration is required at each frequency).

c. Do not change oscillator output level.

Measurement Procedure

a. The facility loss measurement is made on the line side of the office with the protector opened at the line contacts. (The central office equipment and associated wiring must not be included in the measurement).

b. Insert the cable pair between the oscillator and the A-C VTVM as shown in Figure 3B.

c. With oscillator at the sending end set at the desired frequency and have personnel at the receiving end read the A-C VTVM.

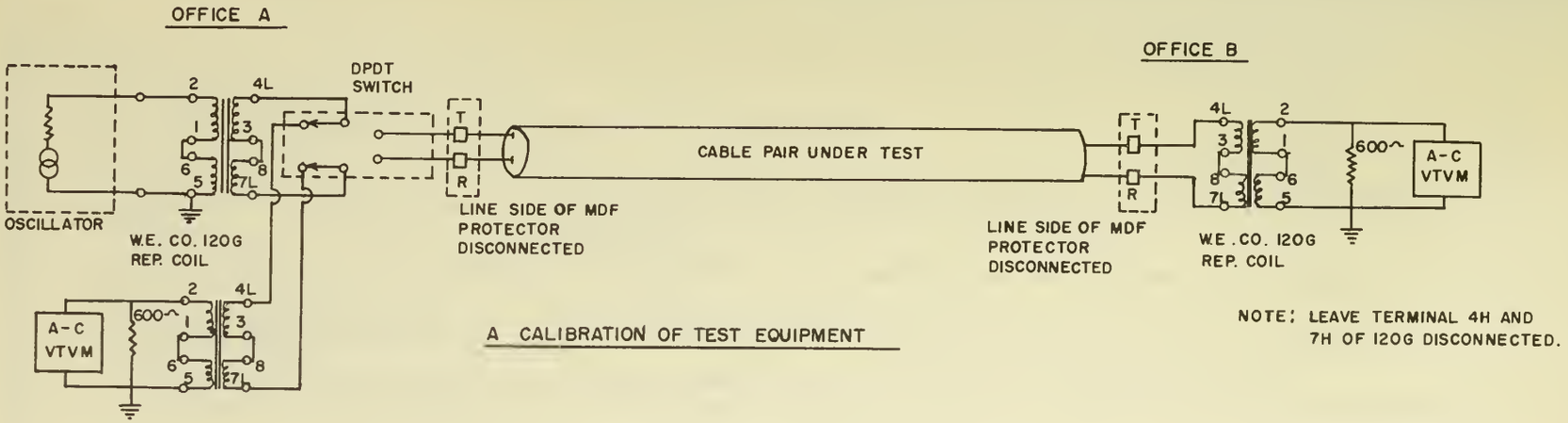
d. The reading in minus dbm of the A-C VTVM at that frequency represents the loss in db of the facility at the same frequency and it includes reflection losses to the terminal equipment at the low and high frequencies.

e. Repeat the above procedure for the remainder of the frequencies under test. Measurements are made at the frequencies of 300, 500, 1000, 2000 and 3000 cps.

f. Enter the results of the measurements for each individual trunk according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

g. Record the facility loss of the line under test which has been previously computed and for the frequencies in paragraph e and enter the results according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

Note 3 of par. 8.21 and Notes 1, 2 and 3 of par. 8.22 are also applicable.



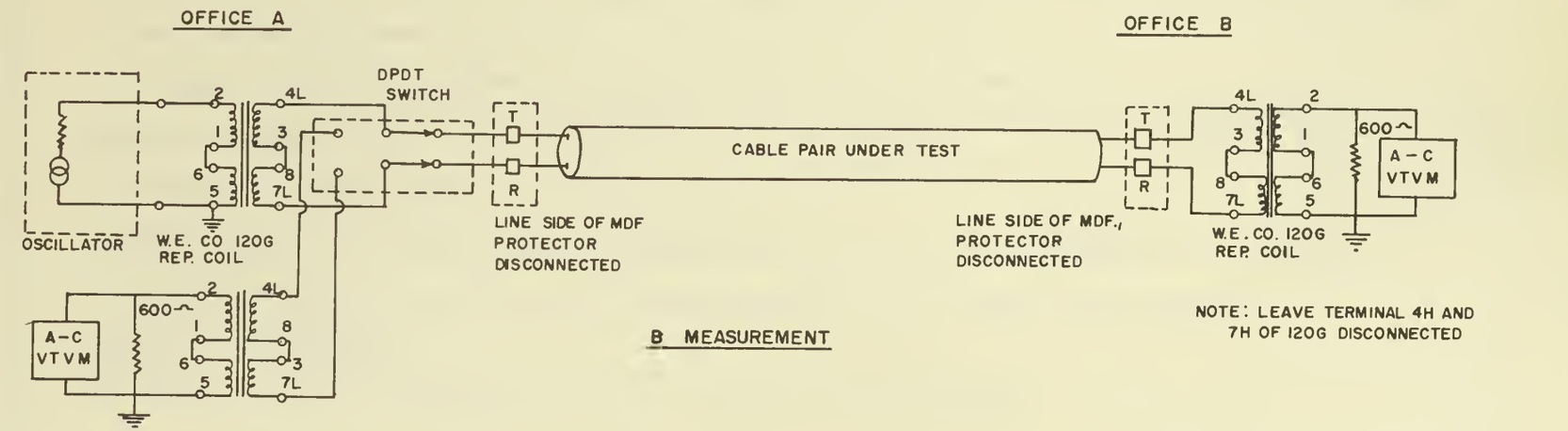


FIGURE 3 CALIBRATION AND MEASUREMENT OF LOADED CABLES USING UNEQUAL RATIO REPEATING COILS

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PROCEDURE FOR CALIBRATION & MEASUREMENT (THIS IS PAR. 8.4 REPEATED HERE FOR CONVENIENCE)

Calibration of Test Equipment

a. Connect the oscillator, the 600 ohm resistor, the 120 H repeating coil and A-C VTVM as shown in Figure 4A.

b. Set the oscillator to the desired frequency and vary oscillator output level control to read 0 dbm on the A-C VTVM. (Calibration is required at each frequency).

c. Do not change oscillator output level.

Measurement Procedure

a. The insertion loss measurement is made on the line side of the office with the protector opened at the line contacts. (The central office equipment and associated wiring must not be included in the measurement).

b. Insert the cable pair between the oscillator and the A-C VTVM as shown in Figure 4B.

c. With oscillator at the sending end set at the desired frequency and have personnel at the receiving end read the A-C VTVM.

d. The reading in minus dbm of the A-C VTVM at that frequency represents the loss in db of the facility at the same frequency and it includes reflection losses to the terminal equipment as well as the junction of dissimilar facilities.

e. Repeat the above procedure for the remainder of the frequencies under test. Measurements are made at the frequencies of 300, 500, 1000, 2000 and 3000 cps.

f. Enter the results of the measurements for each individual trunk according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

g. Record the insertion loss of the line under test which has been previously computed and for the frequencies in paragraph e and enter the results according to frequency in a form similar to Exhibit 1 - Data Record - Voice Frequency Transmission Measurements.

Note 3 of par. 8.21 and Notes 1, 2 and 3 of par. 8.22 are also applicable.

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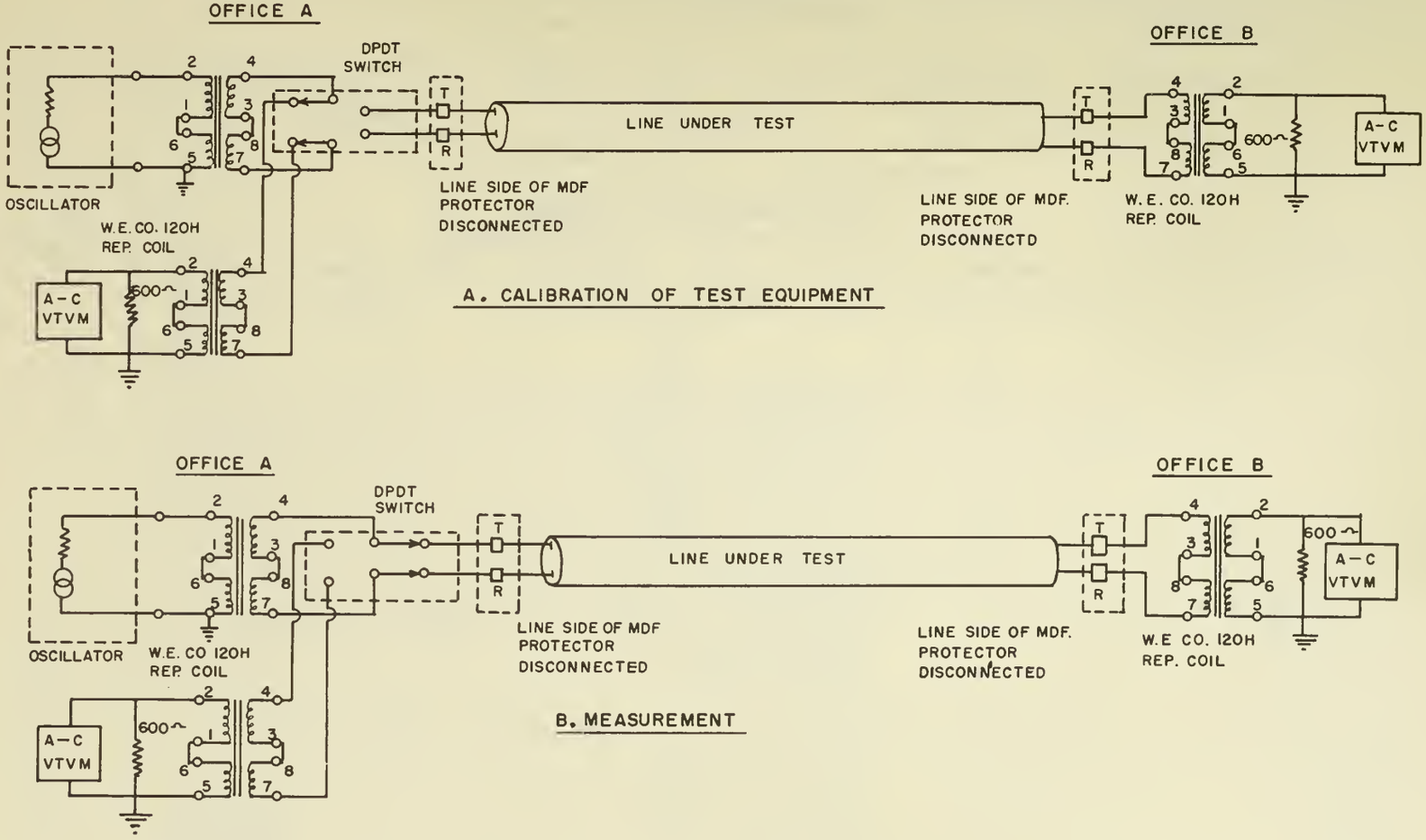
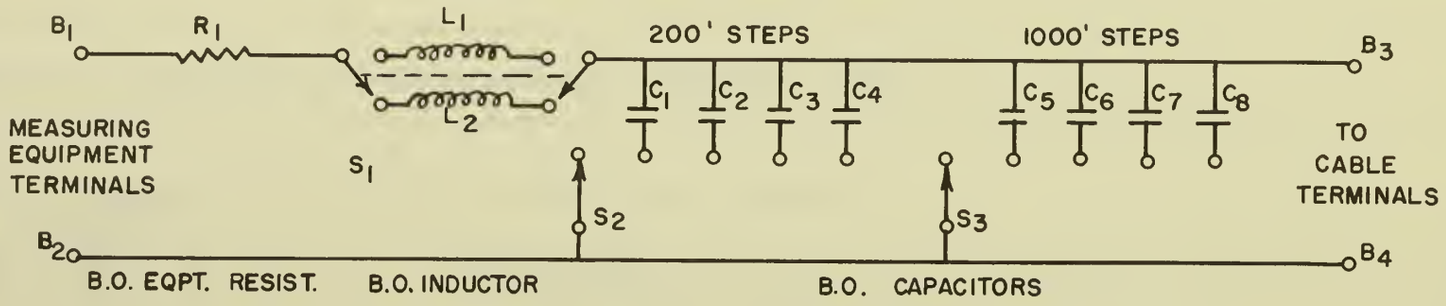


FIGURE 4 CALIBRATION AND MEASUREMENT OF OPEN WIRES LINES

SCHEMATIC DIAGRAM & CONSTRUCTION DETAILS OF IMPEDANCE COMPENSATOR
(SEE FIGURE 2 FOR APPLICATION)



PARTS LIST

R_1	—	400 OHM	1 WATT	± 1%	CARBON	RESISTOR		AEROVOX TYPE CP1 OR EQUIV.	
L_1	—	44 MH	LOADING	COIL	—	FOR	19-H-88 CABLES	W.E. CO., CEECO. OR EQUIV.	
L_2	—	55 MH	"	"	—	"	22-H-88 "	"	" " " "
C_1	—	PAPER OR MICA	CAPACITOR		0.003	MF	± 3%	500 V DCW	EL MENCO-ARCO CO. OR EQUIV.
C_2	—	"	"	"	"	0.006	"	"	" " " "
C_3	—	"	"	"	"	0.010	"	"	" " " "
C_4	—	"	"	"	"	0.013	"	"	" " " "
C_5	—	"	"	"	"	0.016	"	"	" " " "
C_6	—	"	"	"	"	0.032	"	"	" " " "
C_7	—	"	"	"	"	0.045	"	"	" " " "
C_8	—	"	"	"	"	0.064	"	"	" " " "

S_1 — DPDT SWITCH — CUTLER-HAMMER TYPE 7320-K3 OR EQUIV.

S_2, S_3 — SINGLE POLE 6 POSITION ROTARY SWITCH — CENTRALAB TYPE 1401 OR EQUIV.

B_1, B_2, B_3, B_4 — SUPERIOR TYPE DF30 BINDING POSTS OR EQUIV.

POSSIBLE APPEARANCE OF UNIT

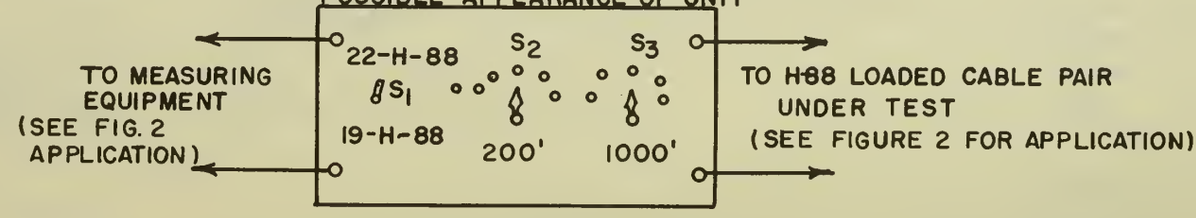


FIGURE 5

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TRANSMISSION OBJECTIVES

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1. INTRODUCTION

1.1 This section provides REA borrowers, consulting engineers and other interested parties with technical information on transmission objectives for use in the design and operation of telephone loop and interoffice trunk facilities. The emphasis in this document, with the exception of Section 4, is on voice frequency transmission parameters to be used in the design of analog and digital facilities. The objective levels contained herein can also be used as guidelines for operating performance, recognizing that certain, older facilities may not fully comply. Noncompliance with these design objectives for in-service facilities should not be construed to mean that a particular facility is necessarily in need of upgrade or replacement. These objectives are advisory.

1.2 The emphasis in Section 4, Voiceband Data Transmission, is distinctly different than that provided in Sections 2 and 3 for the loop and trunk objectives. Here, the stated objectives are performance oriented, and not design oriented.

1.3 This revision replaces both REA TE&CM 415 Issue No. 4 (May 1973) and its Addendum No. 1 (November 1978). The current reissue reflects the increasing deployment of digital facilities in local exchange plant, including use of digital loop carrier systems and remote switching terminals. This revision addresses the post-divestiture and equal access considerations and terminology of today's toll network. A separate discussion is also provided on other more specialized analog parameters that affect data transmission.

1.4 The transmission objectives presented in this TE&CM are the result of research from various sources, such as equipment specifications, ANSI standards, REA publications, reference texts, etc. Existing standards (particularly *ANSI T1.506-1989*) and other industry specifications have been utilized to the extent possible, with some modification where needed to either reflect the more rural nature of REA borrowers' facilities or to modify a performance standard into a design standard. The primary sources of information used in the preparation of this document as well as additional references for reader information have been included in the Selected Bibliography.

1.5 The principal intent of this revision is to present REA borrowers with a single collection of meaningful transmission design objectives while comprehensive national standards for a wide variety of voice frequency parameters are still evolving. As regulatory and national standards are further refined in the specific areas that are addressed in this document, REA borrowers are encouraged to adopt those standards in lieu of the information presented here. As is necessary, this TE&CM will be revised accordingly as other standards develop.

1.6 This document does not address measurement techniques. The reader is advised to consult the IEEE publication, *Standard Methods and Equipment to Measure the Transmission Performance of Analog Voice Frequency Circuits*, as listed in the Selected Bibliography.

1.7 The importance to a local exchange carrier (LEC) of establishing and meeting transmission objectives cannot be underestimated. While an intra-office call may be able to tolerate some variations in noise, loss, etc. and still be acceptable to a local user, toll calls with several links of switching and hundreds of kilometers of traveled distance will be more demanding of both loop and trunk facilities. Connections involving data transfer often will be particularly demanding. With today's emphasis on quality and the clear emergence of competitive local service alternatives available to the larger customers of LECs, maintaining quality transmission for both voice and data circuits is a prime LEC consideration.

2. LOOP OBJECTIVES

2.1 Purpose

2.1.1 Loop facilities, which are largely analog in today's plant environment, contribute most of the total circuit loss in a switched connection even though they are relatively short in length compared to the other facilities involved in an interoffice call. The characteristics of a local loop affect the quality of both local and toll calls. As a result, loop facilities are in many ways the controlling link in terms of transmission quality. This section will address loop objectives under a variety of configurations, both for standard subscriber loops and PBX (private branch exchange) loops.

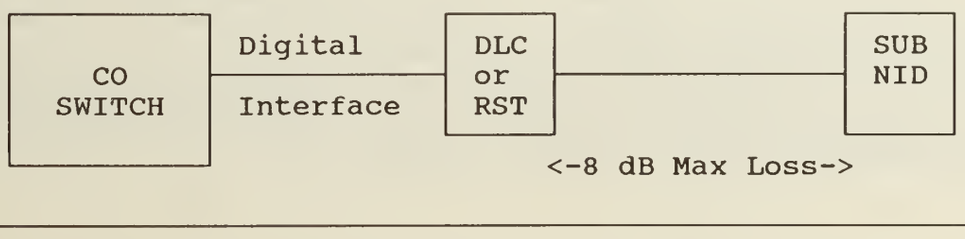
2.2 Loop Loss

2.2.1 The general foundation for loop loss is based upon a maximum of 8 dB loss to the subscriber's network interface device (NID). The specific transmission loss objectives for loop facilities are dependent upon two principal characteristics: 1) the nature of the loop itself, whether it is physical or carrier-derived; and, 2) the nature of the loop interface to the central office switch, whether it is analog or digital. Carrier-derived loop circuits result whenever subscribers are served by either a digital loop carrier (DLC) or an analog carrier (AC) system. DLCs can either have an analog interface on a per subscriber or individual loop basis to the central office (CO) switch; or, a digital interface on a DS1 basis with the CO switch.

2.2.2 Wherever remote switching terminals (RSTs) are deployed in the loop, the interface to the CO switch is on a digital basis. Any loss directly associated with the RST unit is considered as part of the CO switch and not part of the loop. Central office insertion loss and other transmission objectives for digital CO switches are addressed in REA Form 522, *General Specification for Digital, Stored Program Controlled Central Office Equipment*.

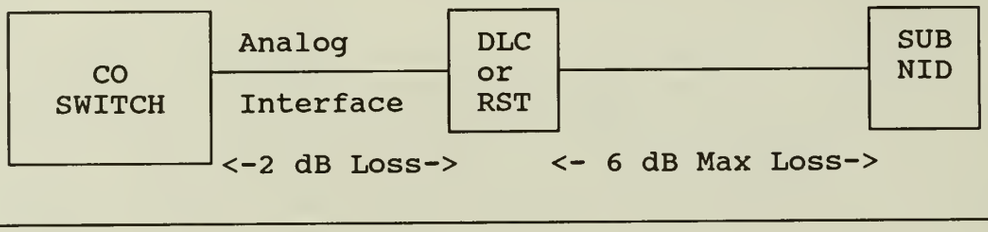
2.2.3 As previously mentioned, the primary basis for all loop loss objectives, regardless of the type of facility or interface, is to maintain the lowest loss possible with a maximum subscriber loop loss from the NID to the CO switch of 8 dB. Where a loop is served by either a DLC or a RST with a direct digital interface to the switch, the full 8 dB of loss is available from the DLC/RST location outward to the subscriber. This situation is depicted in Figure 1A. Should a specific DLC or RST in an integrated mode insert any additional loss into the loop circuit, the 8 dB margin should be reduced accordingly.

FIGURE 1A - MAXIMUM LOSS CARRIER-DERIVED LOOP DIGITAL INTERFACE



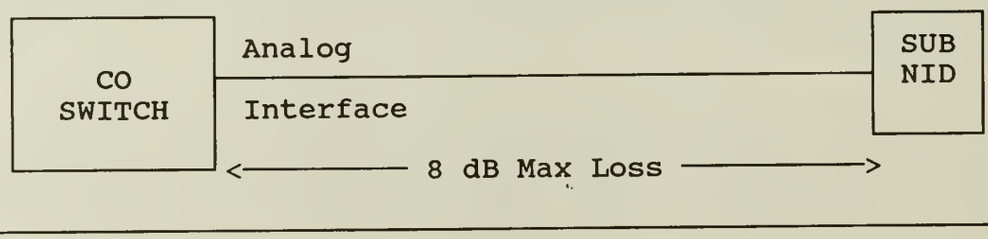
2.2.4 Wherever a DLC or a AC is deployed and the interface to the CO switch is on an analog basis (sometimes known as a universal interface for the DLC), only 6 dB of loop loss is available from the location of the DLC/AC outward to the subscriber. The remaining 2 dB is assigned to the DLC/AC. This configuration is depicted in Figure 1B.

FIGURE 1B - MAXIMUM LOSS CARRIER-DERIVED LOOP ANALOG INTERFACE



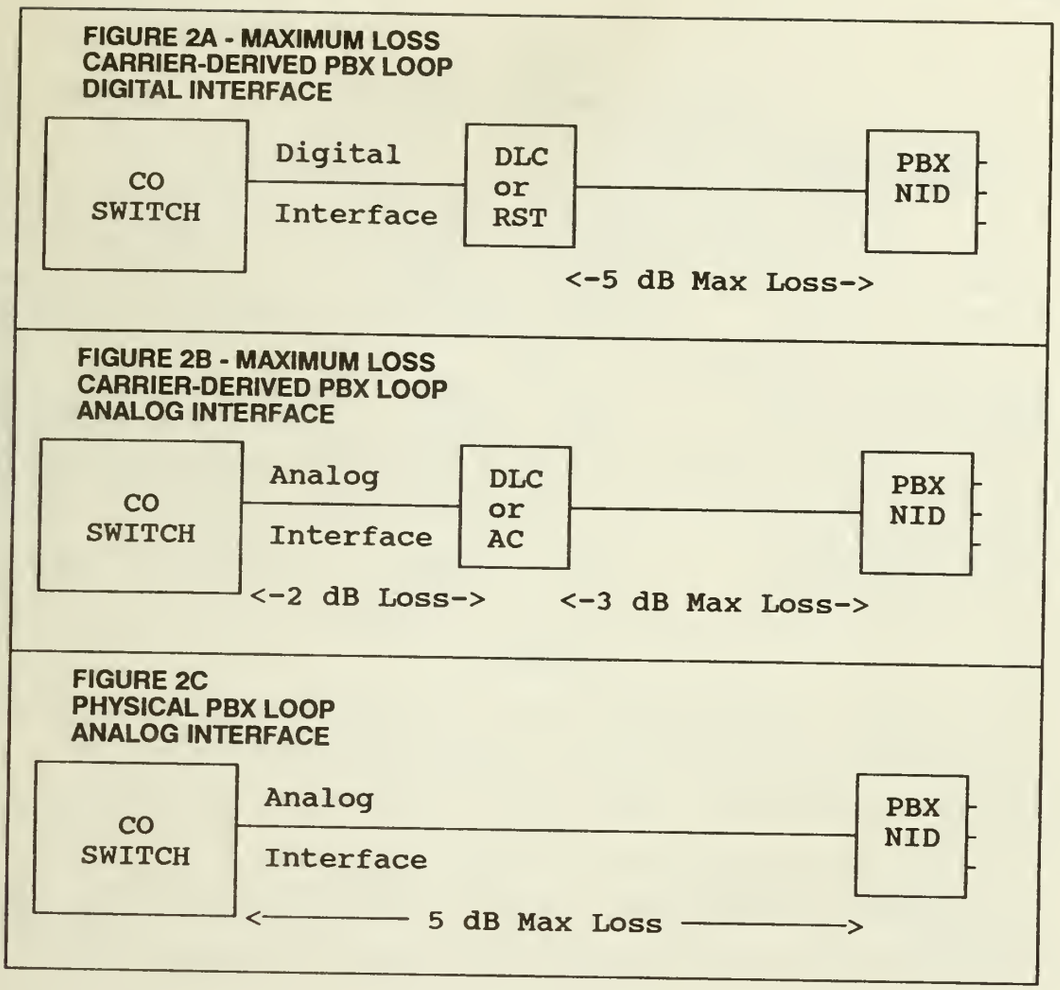
2.2.5 The purely physical analog loop is depicted in Figure 1C. The maximum loss to the CO switch in this situation is 8 dB. Table A summarizes the subscriber loop loss objectives for all of the configurations discussed above.

FIGURE 1C - MAXIMUM LOSS PHYSICAL LOOP



2.2.6 Facilities serving PBXs are treated differently for loss purposes than are standard subscriber loops. This is because a PBX loop functions as a trunking connection instead of a simple subscriber loop connection. PBX circuits serve an additional level of switching and contain their own "loop" facilities beyond the PBX switch in terms of inside building wiring. PBX trunks, therefore, are limited to 5 dB maximum loss, allowing an additional 3 dB for the loop served by the PBX.

2.2.7 As with standard subscriber loops, the distance from the PBX to the CO switch can be extended by using either DLCs or RSTs. With a DLC or RST having a digital interface, the entire 5 dB loss margin is available from the DLC/RST system outward to the PBX NID. This is shown in Figure 2A. If a DLC with an analog interface or an AC is used in this situation, the PBX loop will be limited to 3 dB of loss, as depicted in Figure 2B. Figure 2C depicts the purely physical analog PBX loop. Loss margins for all PBX configurations are also shown in Table A.



2.3 Loop Current

2.3.1 To insure proper operation of customer premises equipment (CPE) at each subscriber, sufficient loop current must be maintained. The loop current objective under adverse conditions (low battery or standby generator) is ≥ 20 mA.

2.4 Loop Noise

2.4.1 The weighted noise objective for subscriber and PBX loops is 20 dBrnC. It is measured at the NID, located at the subscriber's premises. The loop objectives for steady state C-Message noise are independent of the interface to the CO switch and the nature of the loop facility. Loop noise objectives are also outlined in Table A.

2.5 Loop Frequency Response

2.5.1 Frequency response parameters for loop facilities have been defined in terms of a full spectrum requirement and not in terms of a more performance oriented parameter such as Three Tone Slope (TTS). Additional information on TTS may be located in Reference # 1 of the Selected Bibliography. Loop frequency response objectives are outlined in Table A.

TABLE A
LOOP TRANSMISSION OBJECTIVES

Type of Facility	Parameters		
	Loss[2] 1004 Hz	Steady State[3] Noise	Frequency[4,5] Response
Subscriber Lines - Physical	8 dB	20 dBrnC	300-3000 Hz: +1 dB,-3 dB
Subscriber Lines - Carrier Derived w/Digital Interface at CO[1] w/Analog Interface at CO[1]	 8 dB 6 dB	 20 dBrnC 20 dbrnC	 300-3000 Hz: +1 dB,-3 dB 300-3000 Hz: +1 dB,-3 dB
PBX Trunks - Physical	5 dB	20 dBrnC	300-3000 Hz: +1 dB,-3 dB
PBX Trunks - Carrier Derived w/Digital Interface at CO[1] w/Analog Interface at CO[1]	 5 dB 3 dB	 20 dBrnC 20 dbrnC	 300-3000 Hz: +1 dB,-3 dB 300-3000 Hz: +1 dB,-3 dB

NOTES

1 Loss given is that for the physical loop facilities **beyond** the carrier system to the subscriber's network interface device (NID). Carrier systems with a digital interface to the CO switch are assumed to meet the 0 dB interface loss requirements of REA Form 522, "General Specifications for Digital, Stored Program Controlled Central Office Equipment."

2 Maximum value from either the switch or a DLC/AC unit to the subscriber's NID; and, is exclusive of any CO switch-related loss.

3 Steady state noise threshold is a maximum value measured at the subscriber's NID.

4 Loops that contain either nonloaded facilities or loaded loops with long end sections may exceed the stated objectives but should be within +1 dB, -5 dB: 300-3000 Hz.

5 Response objective is specified in terms of a gain and loss range, referenced to a 1004 Hz signal.

2.6 Loop Treatment Options

2.6.1 The application of loop treatment at the central office may be necessary to meet loop transmission objectives. Treatment takes the form of loop extenders which elevate the DC loop voltage, and VF repeaters which provide additional amplification. Treatment should be considered if: 1) the stated loop objectives cannot be met, 2) the loop maximum resistance objectives are exceeded (for information on loop resistance, refer to REA TE&CM 424, *Design Guidelines for Telecommunications Subscriber Loop Plant*), or 3) if a minimum loop current of 20 mA cannot be maintained.

2.6.2 As an alternative to CO loop treatment if subscriber densities are sufficient, the use of DLCs or RSTs on long loops should be considered for a variety of reasons. These include economics, adequate loop current, adequate ringing voltage and minimization of loss and noise. For additional information on loop plant design consult REA TE&CM 424.

3. TRUNK OBJECTIVES

3.1 Purpose

3.1.1 This section will discuss terminology and transmission design objectives to be applied to both analog and digital intraLATA trunk facilities. For REA borrowers and other rural LECs, trunk facilities are largely of a toll nature. However, exceptions exist to this characterization where facilities are provided for extended area service (EAS), special services, operator services or local interoffice links between wire centers or other nearby exchanges.

3.1.2 Because of the significant effects on the telecommunications industry resulting from the divestiture of AT&T, the toll network has undergone many changes in recent years. Traditionally it was a strict hierarchical network operated by a single interexchange carrier (IXC). Today in the realm of interLATA competition and equal access, many carriers operate toll networks which depend upon access to LECs to terminate and route subscriber traffic. Formerly, the interoffice transmission facilities were of the analog variety; today they are largely digital. Even the terminology has changed. This section will address toll transmission objectives from a LATA access perspective while not completely ignoring the predivestiture form of toll network that is still in general use for many REA borrowers.

3.1.3 The trunk transmission design objectives are set forth in five tables: B, C, D, E and F. Those trunks classified as inter-tandem and tandem connecting have more rigorous objective levels. This reflects the desire to maintain a higher quality of transmission both for calls carried over highly segmented routes as well as for strictly toll facilities, such as intertandem. Many of the performance criteria are based upon the nature of the facility, type of access, etc. Therefore, it is recommended that the reader review sections 3.2, 3.3 and 3.4 prior to interpreting the trunk transmission objectives.

3.2 Types of Trunks

3.2.1 Because the technical characteristics and capabilities vary between analog and digital facilities, the actual objectives bear a relationship to the facility and its interface to the switch. This section will briefly define the terms analog trunk, combination trunk and digital trunk.

Analog Trunk - An interoffice facility that is either analog or digital (or a combination of the two) and that terminates both ends in analog interfaces.

Combination Trunk - A digital interoffice facility that terminates one end in a digital interface and at the other end in an analog interface.

Digital Trunk - A digital interoffice facility that terminates both ends in digital interfaces at digital switching systems.

3.3 LATA Access

3.3.1 For some categories of network segments, toll transmission objectives vary depending upon the type of switched LEC LATA access that is made available to the IXC at its point of presence (POP). The four principal types of local exchange access are described below.

Types of Local Exchange Access

Feature Group A (FGA) - A line side connection path from the end office to a specific IXC's POP.

Feature Group B (FGB) - A trunk side connection path (either direct or via a tandem switch) from the end office to a specific IXC's POP.

Feature Group C (FGC) - A trunk side connection path from the end office to AT&T-Communications. Because of its predivestiture origination, used only where Feature Group D access is not available.

Feature Group D (FGD) - A trunk side connection path from the end office to an IXC's POP. Trunking may be either direct or indirect via an access tandem switch. Known as Equal Access.

3.4 Network Configurations

3.4.1 For purposes of discussion, toll network configurations can be placed into two broad categories - predivestiture and equal access. The former is in most cases a Bell System hierarchical network that was modified as a result of the court-ordered divestiture of AT&T to hand off all interLATA traffic at an AT&T point of presence (POP) within the LATA. IntraLATA traffic is carried by either a Bell Operating Company (BOC) or a Independent Telephone Company (ITC). In some cases, groups of ITCs have organized mutually-owned and operated, facility-based intraLATA networks.

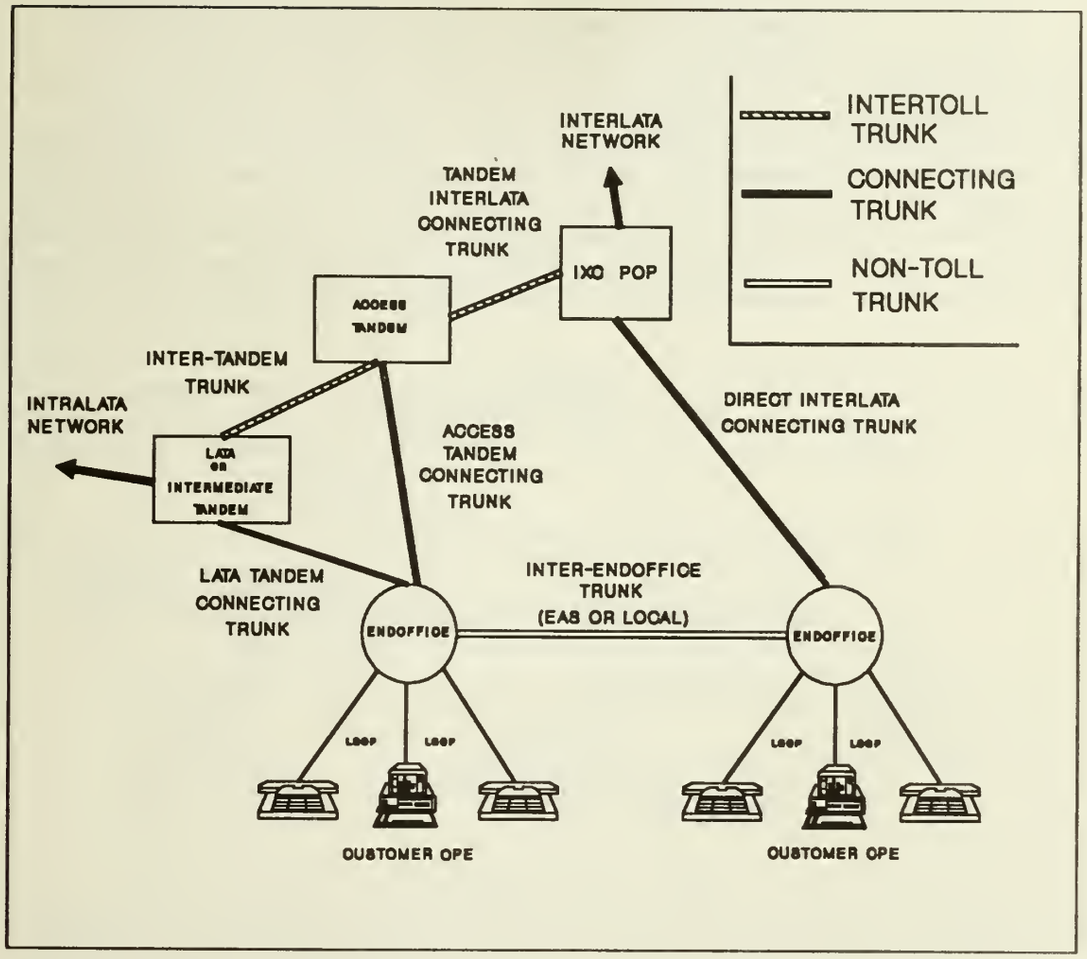
3.4.2 Ultimately, equal access facilities should be universally available to permit Feature Group D connections from all LEC end offices to multiple IXCs. The completion of this process will require some time yet. It is dependent upon a variety of exchange-specific considerations, including end office capabilities, traffic densities, location of IXC facilities and overall economics.

3.4.3 Where equal access (Feature Group D) is not available, Feature Group A lines and/or Feature Group B trunks may exist to provide interim access and distribution of interLATA traffic to IXCs other than AT&T. These forms of access are service alternatives and are not equivalent in operation nor performance to Feature Groups C and D.

3.4.4 Toll trunks in a non-equal access network from the perspective of the REA borrower have been traditionally characterized as either toll connecting or intertoll. Today, the characterization of trunk types has been considerably expanded to represent the wider variety of trunks and configurations possible in an equal access environment coupled with the existence of multiple interexchange carriers (IXCs) and the required separation of intraLATA and interLATA traffic. As a result, the descriptive terms for trunking facilities are often qualified with other prefixes such as direct interLATA or LATA Tandem. The names and the nature of these facilities are shown in Figure 3.

3.4.5 Figure 3 depicts both local end offices and various toll tandem offices and shows the possible types of trunking. The facilities also have been classified into the two previously-used, broad categories of toll connecting and intertoll through use of coded lines. The terminology used here is consistent with that currently used by the BOCs, which interconnect with many REA borrowers and other ITCs.

FIGURE 3
TOLL TRUNKING NETWORK



3.5 TRUNK LOSS

3.5.1 Because of the natural tendency for signals to be reflected in a network wherever impedance discontinuities occur (primarily at 2-wire/4-wire interfaces), loss is intentionally introduced to attenuate these reflected signals. The correct amount of loss attenuates the reflected signal or echo without adversely affecting the magnitude of the primary signal, thereby ensuring adequate voice quality. Control of reflections is particularly important on longer distance toll calls where signal delay and echo are more apparent.

3.5.2 When all interoffice trunking was analog, a national loss plan was developed by the Bell System in the 1950's to maintain minimum overall loss yet minimize the effects of echo on call performance. This plan became known as Via Net Loss, or VNL. VNL is based upon the physical length and type of the facility. Although VNL was used successfully for many years, it sees diminishing use today with the increased deployment of digital trunking facilities. A fixed loss plan, which is largely independent of length, was then developed for digital facilities. Additional information on VNL is available from References # 4 and 5 in the Selected Bibliography, *Notes on the BOC Intra-LATA Networks*.

3.5.3 The fixed loss plan developed for digital networks is specified in terms of two parameters. The first is simply an end-to-end loss from the analog line interface (assuming digital switches) at the originating office to the analog line interface at the terminating office. This is nominally 6 dB for digital toll facilities involving digital offices. The 6 dB is a compromise value that provides low loss on shorter toll connections, yet sufficient loss for longer connections to adequately reduce echo. Digital inter-end office trunks (local or EAS) less than 320 km (200 miles) in length are specified at 3 dB end-to-end loss. Where an analog tandem switch is employed, the fixed loss for toll connecting trunks is reduced to 5 dB. Table B depicts these end-to-end losses.

TABLE B
TRUNK END-TO-END LOSS

Type	Loss[1] End-to End
Inter-End Office (≤320 km)	3 dB
Toll via Digital Tandem	6 dB
Toll via Analog Tandem	5 dB

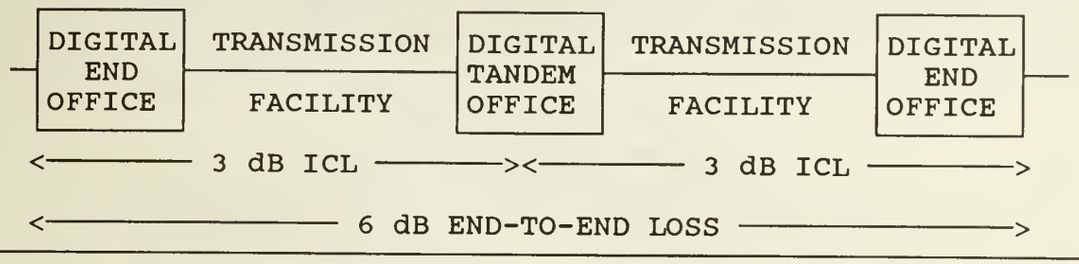
NOTES

[1] Measured from the analog line interface at the originating office to the analog line interface at the terminating office.

3.5.5 The other parameter of the fixed loss plan for digital facilities is Inserted Connection Loss, or ICL. It is part of the end-to-end loss of a connection. Specifically, the ICL is the loss assigned per toll segment, or between switching points, of the overall connection. For digital switches the ICL appears at the decoder stage. Therefore, the ICL of a digital connection cannot be quantified or explicitly measured until the digital signal is decoded. Measurement of the entire end-to-end loss will be affected by the ICLs contained in each segment of the overall connection.

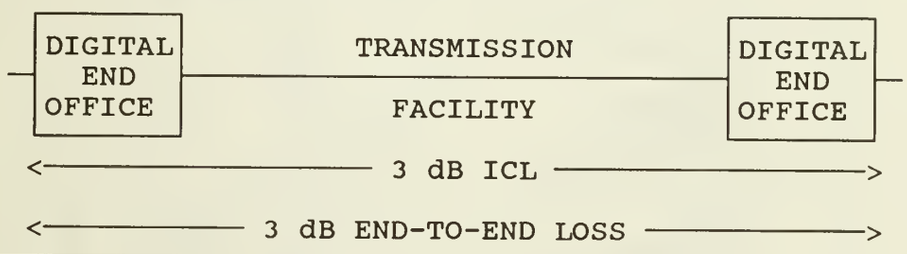
3.5.6 Figure 4A illustrates the ICL in a digital CO to digital CO connection involving one digital tandem switch. Here the end-to-end loss is 6 dB; the ICLs for the two tandem connecting digital toll trunks are 3 dB each. It must be emphasized, however, that the overall end-to-end loss **is not** determined by the numerical addition of all the ICLs. In certain circumstances, such as depicted in Figure 4A, the end-to-end loss can equal the sum of the ICLs; in others it does not. Additional loss beyond the ICL may be inserted to attain the required end-to-end loss. This may occur in the form of loss pads or as the result of certain loss or gain inherent in particular equipment, such as channel banks.

FIGURE 4A
ICL & END-TO-END LOSS
DIGITAL END OFFICE-DIGITAL TANDEM-DIGITAL END OFFICE



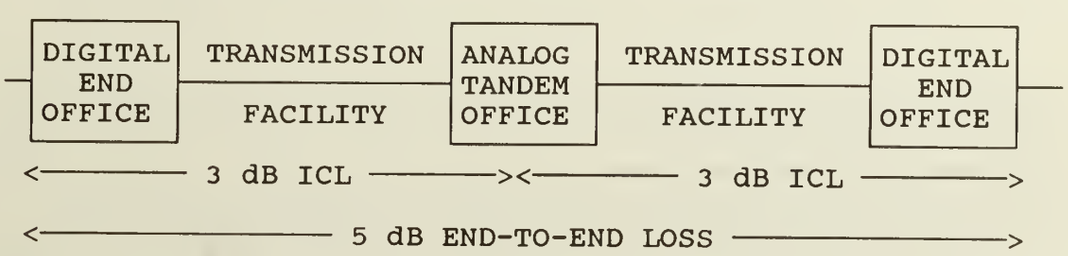
3.5.7 Figure 4B depicts a local end office to end office trunk where the total end-to-end loss is 3 dB. The ICL for this trunk configuration (distances ≤ 320 km) happens also to be 3 dB. The 3 dB ICL occurs at the decode point at the terminating end of the connection.

FIGURE 4B
ICL & END-TO-END LOSS
LOCAL DIGITAL END OFFICE - DIGITAL END OFFICE



3.5.8 For analog switches, the ICL is the difference between the outgoing signal of the originating switch and the outgoing signal of the terminating switch. Loss is normally introduced into this configuration with analog loss pads at the receive-end channel bank. Figure 4C shows the ICL for a digital end office-analog tandem-digital end office connection. Here, the ICL for each individual toll connecting trunk is 3 dB. But, because of the analog tandem switch, the end-to-end loss is 5 dB.

FIGURE 4C
ICL & END-TO-END LOSS
DIGITAL END OFFICE-ANALOG TANDEM-DIGITAL END OFFICE



3.5.9 In general, the ICL for most connecting trunks is 3 dB, regardless of whether analog, digital or combination facilities are involved. Long inter-end office facilities are specified at 6 dB, inter-tandem generally at 0 dB and tandem connecting at 3 dB. Table C depicts the ICL values for these trunks and others. It also provides ICL values for the various forms of inter-LATA access trunks. References # 4 and 5 in the Selected Bibliography provide additional information on ICL.

TABLE C
TRUNK TRANSMISSION
INSERTED CONNECTION LOSS (ICL)

Type of Facility	Loss[1]
I. NON-TOLL[2]	
Inter-End Office (≤ 320 km)	3 dB
II. TANDEM CONNECTING	
Access Tandem Connecting	
Digital	3 dB
Combination	3 dB
Analog (≤ 320 km)	3 dB
Direct InterLATA Connecting	
Digital	3 dB
Combination	3 dB
Analog[3]	3 dB
LATA Tandem Connecting	
Digital	3 dB
Combination	3 dB
Analog (≤ 320 km)	3 dB
III. INTER-TANDEM	
Inter-Tandem	
Digital	0 dB
Combination	1 dB
Analog	VNL
Tandem InterLATA Connecting	
Digital	0 dB
Combination	0 dB
Analog[4]	0 dB

NOTES

1 Loss levels provided are for both Feature Group C (AT&T) and Feature Group D Access, except where noted. Analog loss values are for facilities with gain.

2 The NON-TOLL Category also includes operator, EAS and other special service trunks.

3 Feature Group C Access (AT&T) loss objective for **analog** Direct InterLATA Connecting Trunk is VNL + 2.5 dB.

4 Feature Group C Access (AT&T) loss objective for **analog** Tandem InterLATA Connecting Trunks is VNL.

3.6 TRUNK NOISE

3.6.1 The noise objectives for trunk circuits are specified as a short-term, average noise level performed on an idle channel at the analog interface. The measurement is C-message weighted to more accurately reflect the relative responses of both the human ear and a standard telephone set. The measured noise level is also referenced to a standard noise power of -90 dBm, or 10^{-12} watts. Objective noise levels in units of dBrnC0 for trunking facilities are outlined in Table D.

TABLE D
STEADY STATE OBJECTIVE NOISE LEVELS FOR TRUNKS

Type of Facility	Noise Objective[1,2]
I. NON-TOLL	
Digital Combination/Analog	26 dBrnC0
0 -100 km	30 dBrnC0
100-200 km	32 dBrnC0
II. TANDEM CONNECTING	
Digital Combination/Analog	24 dBrnC0
0 -100 km	28 dBrnC0
100-200 km	30 dBrnC0
III. INTER-TANDEM	
Digital Combination/Analog	24 dBrnC0
0 -100 km	28 dBrnC0
100-200 km	30 dBrnC0

[1] Objective level is defined as a recommended minimum for facility design.

[2] Where digital switches employ digital loss pads, the stated objective may be increased by 1 dBrnC0.

3.7 TRUNK RETURN LOSS

3.7.1 Return Loss is a measure of a signal's reflected power back to the originating end of a network. It is equal to the ratio of the transmitted power to the reflected power, in dB. The reflection occurs as a result of impedance mismatches at network discontinuities, such as at a 4-wire/2-wire interface. The return loss is commonly measured in two frequency-weighted bands. It is then referred to as Echo Return Loss (ERL) and Singing Return Loss (SRL). ERL measures the loss over the middle of the voiceband where echo is most likely. SRL measures the return loss at the edges of the voiceband where singing or oscillations tend to occur.

3.7.2 It is important to ensure adequate return loss at tandem switch locations where 4-wire/2-wire interfaces are sometimes located to maintain proper balance. If all end offices, tandem switches and trunks are 4-wire, then trunk return loss need not be a concern. Where necessary, return loss measurements are performed on tandem connecting trunks to and from end offices connected via 2-wire trunks. This is known as terminal balance. Terminal balance objectives for trunking facilities are shown in Table E.

TABLE E
TERMINAL BALANCE TRUNK OBJECTIVES[1]

Type of Facility	Return Loss ERL	SRL
TOLL CONNECTING TRUNKS		
Digital	23 dB	17 dB
Combination/Analog	18 dB	12 dB

NOTES

[1] Objective level is defined as a recommended minimum for facility design.

3.8 TRUNK FREQUENCY RESPONSE

3.8.1 Frequency response parameters for toll trunks have been defined in terms of a full spectrum requirement and not in terms of a more performance-oriented parameter such as Three Tone Slope (TTS). Additional information on TTS may be located in Reference # 1 of the Selected Bibliography. Frequency response objectives for trunk facilities are outlined in Table F.

TABLE F
TRUNK FREQUENCY RESPONSE OBJECTIVES[1]

Type of Facility	Frequency[2] Response
Digital	300-3400 Hz: +1 dB, -3 dB 600-2400 Hz: ±1 dB
Combination/Analog	300-3400 Hz: +1 dB, -4 dB 600-2400 Hz: ±1 dB

NOTES

[1] Objective level is a recommended minimum for facility design.

[2] Response objective is specified in terms of a gain and loss range, referenced to a 1004 Hz signal.

4. VOICEBAND DATA TRANSMISSION OBJECTIVES

4.1 Purpose

4.1.1 In addition to the more standard noise and loss parameters, additional analog characteristics can be measured and controlled on voiceband transmission facilities in order to ensure adequate data transmission. Proper control of these parameters can play a major role in the performance of data modems to accurately transmit and receive data through the public network on both physical and carrier facilities. Although these characteristics are to some extent determined in the design of transmission equipment, equipment malfunctions and harmful external influences may be detected through proper observation and measurement. Often, a single cause may be common to the simultaneous occurrence of one or more parameters exceeding the defined objectives. This section will briefly describe each of the voiceband parameters. The performance objectives are noted in Table G. For information on actual measurement techniques, the reader is referred to Reference # 8 in the Selected Bibliography.

4.1.2 The objective level for each parameter outlined in Table G was developed from the Service Affecting Limits (SALs) and other supporting information contained in *ANSI Standard T1.506-1989*. The SALs are designed for use in achieving adequate voiceband data transmission with modems operating up to 9600 bits/second. The limits are to be applied in measuring the performance of primarily trunk facilities, but some of the parameters may also be useful for evaluating loop performance. Since these are recommended minimum values, no distinction has been made between digital, analog and combination facilities. Digital facilities, however, would be expected to exhibit somewhat better performance in general than the other two facility types.

4.2 Amplitude Jitter

4.2.1 Amplitude Jitter is any fluctuation in the peak amplitude value of a fixed tone signal at 1004 Hz from its nominal value. Amplitude Jitter can be measured in two separate frequency bands, 4-300 Hz and 20-300 Hz. The wider 4-300 Hz band is important where modems that employ echo cancelling capability are used. Table G provides Amplitude Jitter objectives for both the 4-300 Hz band and the 20-300 Hz band. Amplitude Jitter is measured in terms of percent peak amplitude variation of signal amplitude.

4.3 Signal to C-Notched Noise

4.3.1 Signal to C-Notched Noise (S/CNN), or Signal to Distortion (S/D) Ratio, is the logarithmic ratio expressed in dB of a 1004 Hz holding tone signal compared to the C-message weighted noise level. Because the noise measurement is performed with a holding tone, the receive band is notched or attenuated around the 1004 Hz contour (C-message weighted) to remove this tone, leaving only the resulting noise or distortion. The holding tone can be input at either -13 dBm (the level that more closely approximates an actual data modem) or -16 dBm (the level used in many automated test systems).

4.3.2 S/CNN can be one of the most important transmission parameters affecting the performance of data transmission. Other parameters such as harmonic distortion, quantizing noise and jitter can also contribute to excessive CNN. The use of digital loss pads for level

settings is also a source of CNN. The S/CNN objectives in Table G are provided at typical modem signal levels of -13 dBm0.

4.4 Envelope Delay Distortion

4.4.1 Envelope Delay Distortion (EDD) is a measure of the linearity or uniformity of the phase versus frequency characteristic of a transmission facility. (It is also known as relative envelope delay, or RED.) If EDD is sufficiently high, various frequency components will travel at a different rate of speed with different arrival times, causing successively transmitted data pulses to overlap at the receive end. The resulting phenomenon is known as intersymbol interference and may cause significant data errors.

4.4.2 EDD is specifically defined as the delay relative to the envelope delay at a reference frequency, commonly 1704 Hz. It is typically measured at two frequencies, one low and one high in the voiceband. The objective levels for EDD in units of microseconds delay are given in Table G for 604 Hz and 2804 Hz. Remedial solutions to excessive EDD can be provided through use of improved modems with equalization or by line conditioning performed by the LEC or IXC. EDD can also be measured and quantified through Peak to Average Ratio (P/AR) techniques.

4.5 Impulse Noise

4.5.1 Impulse Noise is a measure of the presence of unusually large noise excursions of short duration that are beyond the normal background noise levels on a facility. It is typically measured by counting the number of occurrences beyond a particular noise reference threshold in a given time interval. The noise reference level is C-message weighted. Transient signals originating from various switching operations are a common source of impulse noise.

4.6 Intermodulation Distortion

4.6.1 The Signal to Intermodulation Distortion ratio (S/IMD) is a measure of the distortion produced by extraneous frequency cross products, known as intermodulation products, when a multi-tone signal is applied to a system. The test process is the 4-tone method.

4.6.2 IMD is caused by the system nonlinearities acting upon the harmonic frequencies produced from an input of multiple tones. The products resulting from IMD can be more damaging than noise in terms of producing data transmission errors.

4.6.3 Specifically, IMD is measured as a signal to distortion ratio and is expressed as the logarithmic ratio in dB of the composite power of four resulting test frequencies to the total power of specific higher order distortion products that are produced. The higher order products are measured at both the 2nd order and the 3rd order and are designated R2 and R3, respectively. The four frequency testing for IMD is produced with four tones of 857, 863, 1372, and 1388 Hz input at a composite power level of -13 dBm0.

4.7 Phase Jitter

4.7.1 Phase Jitter (PJ) is any fluctuation in the zero crossing of a fixed tone signal in the voiceband. It is measured in terms of either degrees peak-to-peak (°p-p) or in terms of a Unit Interval, or UI. One UI is equal to 360° p-p. PJ measurements are typically performed in

two nominal frequency bands: 1) 20-300 Hz and 2) either 2-300 Hz or 4-300 Hz, the latter being more appropriate for transmission with modems employing echo-cancelling techniques. Table G sets forth phase jitter objectives in terms of °p-p for the 4-300 Hz band the 20-300 Hz band.

4.7.2 PJ plays a major role in the error performance of data transmission wherever phase modulation techniques are used. The influence of power lines and other facilities through electromagnetic induction is a common cause of PJ. Digital facilities with PJ can be remedied through control of C-notched noise, impulse noise and DS1 timing.

TABLE G
VOICEBAND DATA TRANSMISSION OBJECTIVES[1]

Parameter	Value
Amplitude Jitter[2]	(maximum)
20-300 Hz	5 %
4 -300 Hz	6 %
Signal to CNN[2]	(minimum)
	31 db
Envelope Delay[3] Distortion	(maximum)
604 Hz	1500 μs
2804 Hz	1000 μs
Impulse Noise[2,4]	(maximum)
	65 dBrnC0
Signal to IM Distortion	(minimum)
R2	40 dB
R3	40 dB
Phase Jitter	(maximum)
20-300 Hz	6.5° p-p
4 -300 Hz	10.0° p-p

NOTES

[1] Minimum performance objectives for in-service trunk facilities. Equivalent to the Immediate Action Limit (IAL) as defined in "ANSI Standard T1.506-1989."

[2] Measured with a 1004 Hz tone at -13 dBm0.

[3] Envelope Delay Distortion objectives are shown in microseconds delay which are relative to the delay at 1704 Hz.

[4] Impulse Noise objectives are based upon a maximum of 5 counts in a 5 minute period at equal or greater than the indicated noise thresholds.

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BOOKSTACKS
DOCUMENTS

VOICE FREQUENCY LOADING FOR TRUNK CABLES

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1. GENERAL

1.01 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with information for use in the design and construction of REA borrowers' telephone systems. It discusses in particular the engineering

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and transmission considerations involved in the selection, layout and construction of trunk cable loading systems which, in combination with voice-frequency repeaters, are required in order to meet transmission objectives. This section also provides technical information for the correct interconnection of different types of loading systems when necessary. Quantitative information is also given in the tables contained herein for carrying out the required transmission computations. Though this section assumes the use of cable having twisted pairs insulated with polyethylene, information on paper insulated cables is included in Table I.

1.02 This section is reissued to reflect various changes in transmission practices necessitated by the conversion to direct distance dialing,[1] the operation of EAS trunks at lower losses, and the general trend toward improved transmission objectives. Economically priced transistorized voice frequency repeaters capable of high gain, more economical facilities and the improved characteristics of D-66 loading systems allow fuller utilization of finer gauge cables to make these objectives economically realizable. This section supersedes Section 431, Issue No. 1, dated May 1955 and all addenda thereto.

1.03 Importance of Loading System Uniformity

1.031 The successful operation of voice frequency repeaters in both extended area and toll trunk plant, requires that close attention be paid in design and construction to obtain nearly uniform spacing of loading points. Non-uniformity in the loading spacing lowers the structural return loss,[2] which in turn reduces the gain capability of the repeater. Non-uniformity in cable mutual capacitance in different cable reels also lowers the structural return loss. Cable mutual capacitance and loading coil uniformity are obtained in REA borrowers' plant by suitable cable and loading coil specifications.

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1. Refer to "Notes on Distance Dialing" 1961, by the American Telephone and Telegraph Company, Engineering Department.

2. For the definition of "structural return loss" and a full discussion refer to REA TE & CM-445, "How to Make Structural Return Loss Measurements."

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1.032 Over the past years the transmission losses to which trunk plant has been engineered have been constantly decreasing due to the growing trend toward improved and expanded services. Operation of trunks at increasingly lower net losses requires that voice frequency repeaters with increased gain capability be available and that the cable plant, including the type of loading system used, over which such equipment will operate be capable of effectively utilizing this increased gain. In turn, the ability of the cable plant to utilize to advantage the gain capability of the repeaters depends among other factors, not only on the type of loading system selected but on the care and methods used in spacing the loading points during the design, staking, and construction of the plant.

1.033 Because of the necessity for dealing with practical plant layout conditions due to conditions of terrain or other local factors, precise loading spacing is not usually attainable. Paragraphs 3.04 and 3.05 give the maximum loading spacing deviations which are considered tolerable. It should be kept in mind that the deviations discussed in these paragraphs are not design or target values, but the maximum which are allowable. For new construction where the terrain and other local factors permit, every effort should be made not only during the design stage but especially during staking and construction to improve the deviation limits of these paragraphs. Where these steps are taken the benefits of higher repeater gains, reduced repeater and plant maintenance and future flexibility should improvements or special services become necessary are more easily attainable.

1.034 Impedance irregularities with accompanying low return losses resulting from errors in loading spacing deviations, missing, reversed winding or doubled-up coils, incorrect value loading coil inductance, bridged taps or other causes, adversely affect the performance of repeaters operating over the cable. Of the different faults listed above, the irregularities resulting from incorrect load spacing may be the most difficult to correct due to the fact that they become manifest as minor or finite irregularities whereas the effect of the others is to produce major irregularities which totally disrupt the performance of voice frequency repeaters. Major irregularities as a result of missing, reversed, doubled-up or incorrect value

loading coils or long bridged taps can be detected and located by using the measuring procedures set forth in REA TE & CM-408, "Facility Requirements for Voice Frequency Repeatered Trunks," paragraphs 10 and 11. This assumes that an impedance irregularity has a single cause. Where several causes are involved the detection procedures become more complex. However, once the major irregularities have been found and corrected, the final structural return loss will be reduced by the loading spacing deviations present. In general, detection and location of smaller impedance irregularities requires personnel skilled in the art and equipped with highly specialized test equipment. In addition, the procedures are invariably time consuming and for these reasons not readily adaptable to REA borrowers' plant. In buried plant construction the correction of load spacing deviations may not always be practical or economical due to the limited number of pedestal locations. For these reasons it is again to be emphasized that, due to the complexity, cost and highly specialized nature of the work involved in detecting, locating and correcting impedance irregularities the approach should be to prevent these irregularities from occurring rather than in trying to correct them afterwards. During the ACD* and construction stages this may be accomplished as follows:

(a) Consider the importance of uniform load spacing.

(b) Make the design somewhat more conservative than the maximum allowed.

(c) Use qualified personnel for staking plant.

(d) Provide proper and adequate supervision during construction.

(e) Utilize effectively the sequential marking of cables.

1.035 Since voice frequency repeaters are purchased on a guaranteed performance basis from contractors other than those which construct the outside plant facilities, measurements prior to repeater installation are

* Area Coverage Design

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required on the as-built plant to determine its suitability to repeater application. REA Bulletin 383-2, "Acceptance Tests--Outside Plant," establishes the extent of required testing, and REA TE & CM-408, Figure 2, and REA TE & CM-445, Figures 11A and 11B, provide step-by-step procedures for making the actual measurements.

2. LOADING AND LOADING SYSTEMS

2.01 Theory of Loading

2.011 The primary[1] purpose of inductance coil loading is to improve the transmission of intelligence by substantially reducing the circuit attenuation, and by making the circuit attenuation approximately uniform throughout a predetermined frequency-band. These transmission benefits are obtained by serially inserting coils having uniform inductance values at regularly recurring intervals along the circuit, but are limited to a frequency-band below the loading cutoff frequency. Above the loading cutoff frequency, there is a substantial suppression of transmission.

2.012 The attenuation[2] improvement obtainable with loading corresponds somewhat to the increase in impedance that results from the increase in inductance. This can be understood from the fact that in the (low-impedance) non-loaded circuit, the series dissipation losses which are proportional to the square of the line current are ordinarily very large relative to the dielectric dissipation (i.e. shunt) losses which are proportional to the square of the line potential. When the line impedance is increased a suitable amount by the loading, the decrease in series losses is much greater than the increase in shunt losses. Economic considerations usually prevent the use of high loading impedances which would result in shunt losses becoming as great or greater than the series losses. As an illustration, an exchange type 22-gauge cable results in less loss when, for example, D-66 or H-88 loaded (approximately 0.8 db per mile at 1000 cps) than a similar

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1, 2. "Inductive Loading for Bell System Telephone Circuits" by T. Shaw, Bell System Technical Journal, January 1951.

capacitance 19-gauge cable which is non-loaded (approximately 1.3 db per mile at 1000 cps). Therefore it becomes more economical to use loaded 22-gauge cable pairs than 19-gauge pairs non-loaded.

2.013 The inductance also offsets the effect of the cable capacitance which is always present between the wires of a cable. This results in a more natural sounding circuit since the effect of capacitance between wires is to cause more loss for the higher voice frequencies. The combination of the value of coil inductance, the spacing between loading coils and the mutual capacitance of the cable between loading points determine the attenuation, impedance and band pass characteristics of the particular loading system.

2.014 Another way of viewing inductive loading is by comparing it to a simple low pass filter where the inductance of the loading coil comprises the series arm while the cable mutual capacitance comprises the shunt arm. In a simple low pass filter and further, one where components have no losses, there is a frequency band where the attenuation is zero (passband) and another band where it is infinite (rejection band). The point where the two bands cross is termed "cutoff frequency." Unlike a simple one section low pass filter, a loaded cable behaves like a group of such filters in cascade with the capacitance and inductance of each loading section making up one filter section. The individual filters (loading sections) must be uniform in order to accomplish the purpose intended, that is, each loading section must look reasonably close to the others in spacing, capacitance and inductance.

2.015 If the above uniformity characteristics in any section in the multisection low pass filter (loaded cable) are altered, the performance characteristics of the filter are changed and the results are reflected in the entire loaded cable. Therefore, a change in the inductance or the capacitance of only one loading section degrades the band pass performance of the low pass filter action. Some common plant items which may bring this about are:

(a) Reversed, missing, doubled-up or incorrect value loading coils.

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(b) Bridged taps between coils, doubled-up cable pairs or extra long or short loading sections.

(c) Irregular (non-uniform) loading spacing.

In summary, in order to effectively utilize the transmission advantages of loading, the loading must be properly designed, installed, and maintained.

2.016 A non-phantomed loading coil has two separate balanced windings coupled to the same magnetic core. The inductance of each winding of the loading coil, when the other winding is open circuited, has approximately the same value. The total inductance of a loading coil when both of its windings are connected series-aiding (this is the normal inductance which results when the coil is correctly wired to the cable pair). is approximately four times the inductance of the individual windings. Obviously, therefore, the additional inductance contribution of the individual windings by virtue of being coupled to a common core is approximately fifty percent of the total inductance. This additional inductance is known as "mutual inductance" and it acts to aid or negate the remaining inductance contributed by the individual windings. For this reason, reversing one winding with respect to the other must be avoided since this greatly reduces the total series inductance provided by the loading coil.

2.02 Designation of Loading Systems

2.021 Loading systems are designated by a letter signifying the full section length between loading points followed by a numeral denoting the inductance of the coil in millihenries. In voice frequency loading systems the full section lengths generally used are 6000 and 4500 feet with coil inductances of 88 and 66 millihenries. The following table covers some of these loading systems:

Designation	Coil Spacing-feet	Coil Inductance-mh
D-66	4500	66
H-88	6000	88
D-88	4500	88
B-88	3000	88
B-44	3000	44
H-44	6000	88

The cable mutual capacitance associated with the above loading systems usually has a nominal capacitance of 0.083 microfarads per mile. Such cable is referred to as "exchange type" and abbreviated "HC" in sections for convenience. Loading systems, however, may also be used with "low capacitance" (toll-grade) cable which has a capacitance of 0.062 or 0.066 microfarads per mile. To distinguish the application between loading systems of the exchange and the toll type, the designation of "LC" is usually attached after the loading system designation for the latter application. For example, the designation 19-H-88-LC refers to the application of H-88 loading on 19-gauge low capacitance cable.

2.022 The above designations refer to circuits from which no additional or "phantom" circuits are being derived. In situations where phantom circuits are being derived there is an additional designation of the loading system to denote the value of coil inductance for the phantom circuit. For example, the designation H-88-50 indicates that the side circuit is being loaded with 88 millihenry coils at every 6000' while the phantom circuit utilizes 50 millihenry coils spaced at the same intervals. Over the past years the practice of "phantoming" has gradually been discontinued.

2.03 Transmission Characteristics of Loading Systems

2.031 The most significant transmission characteristics of loading systems are:

(a) In the passband region, there is a reduction in the magnitude of the attenuation.

(b) The attenuation is reduced but not eliminated due to the cable and coil resistance and some cable conductance dissipation.

(c) There is a cutoff frequency by virtue of the lumped loading. (Distributed loading does not display this characteristic.)

(d) The impedance has been raised.

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(e) At the cutoff frequency and beyond, the attenuation of the loaded cable is higher than that of non-loaded cable.

(f) Increasing the loading coil inductance or loading section cable mutual capacitance, or both, lowers the cutoff frequency.

(g) For a given loading spacing, increasing the loading coil inductance decreases the attenuation per mile while increasing the cable mutual capacitance increases this attenuation.

2.032 Quantitatively, the attenuation, impedance and cutoff frequency characteristics of loaded cable are given by the following simple expressions for the passband region where the loaded cable behaves almost exactly like a corresponding smooth line. The precise formulas for attenuation and impedance are much more complex than the ones shown. For 1000 cps computations, however, formulas (a) and (b) can be used to a very good approximation. In fact, formulas (a) and (b) are reasonably good up to 0.6 of the cutoff frequency. (See formula (c) and Figures 2 to 6.) The units are resistance in ohms, capacitance in farads and inductance in henries, and they must be expressed for the same unit length. A mile basis is normally used for formulas (a) and (b).

(a) The attenuation in db per mile is:

$$\left[a = 4.34R\sqrt{\frac{C}{L}} \right]$$

R includes both the cable and loading coil resistance.

(b) The magnitude of impedance in ohms is:

$$\left[Zo = \sqrt{\frac{L}{C}} \right]$$

(c) The cutoff frequency in cps is:

$$\left[Fc = \frac{1}{\pi\sqrt{LC}} \right]$$

In formula (c) both L and C must be expressed on a full loading section basis and in addition L includes the cable pair inductance of approximately one millihenry per mile. For an 0.083 microfarad per mile cable the cutoff frequency is about 3500 cps for H-88 and 4600 cps for D-66 loading.

2.033 Representative line constants for 19 gauge and 22 gauge exchange type and low capacitance plastic-insulated cable pairs are tabulated below. The unit of length is taken as one statute mile. These constants are practically independent of frequency in the passbands of D-66 and H-88 loading systems. The resistance per mile of the soft copper wires of the cable varies with temperature and the tabulated resistances are for 68°F. (20°C). In the voice frequency range, the resistance is about R (1 ± .0022 t) where R is the resistance at 68°F. and t is the change in temperature in degrees Fahrenheit. For t + ± 50 degrees, the resistance is R (1 ± .11).

Line Constants per Mile @ 68°F.

Gauge	HC or LC	Resistance Ohms	Inductance Millihenries	Conductance Micromhos	Nominal Capacitance in Microfarads
19	HC	85	1.0	1.0	.083
22	HC	171	1.0	1.0	.083
19	LC	85	1.0	1.0	.066

2.0331 Loading coils not only add series inductance in the cable pairs but series resistance as well. These resistances are tabulated below for a temperature of 68°F.

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Typical Resistance of a Loading Coil in Ohms

Frequency-cps	Loading Coil Millihenries	
	66	88
100	6.2	7.9
300	6.4	8.1
500	6.6	8.3
1000	7.1	8.7
1500	7.5	9.2
2000	8.0	9.8
2500	8.6	10.6
3000	9.5	11.5
3500	10.4	12.6
4000	11.7	14.2

2.034 The above line constants were used to calculate the transmission loss in db per mile for the passbands of D-66, H-88 and other loading systems. These losses are plotted against frequency on attached Figures 2 to 6. For a given loading system such as 22 gauge D-66, the losses in db per mile vary approximately directly with the resistance per mile which, in turn, varies with temperature as discussed under Paragraph 2.033.

2.035 The characteristic impedance of a loaded circuit is theoretically the impedance as measured at a terminal of the circuit when it stretches to infinity. However, a circuit of finite length may be terminated in a proper precision balancing network at one end and then the characteristic impedance will almost be exactly as measured at the other end. The characteristic impedance depends upon the fraction of a loading section which the measuring instrument faces. As a reference, characteristic impedances for mid-section are quoted. Figure 6 shows mid-section characteristic impedances plotted against frequency for 22 and 19 gauge exchange type cables D-66 and H-88 loaded. It should be noticed that for exchange type cables the impedance for H-88 loading rises much more rapidly with increasing frequency than that for D-66 loading. A rapid rise with frequency is undesirable from both trunk and subscriber loop transmission considerations since this rise reduces available repeater gains and degrades voice frequency response characteristics.

2.04 Applications of Loading Systems

2.041 The D-66 loading system is the type of loading generally recommended for use in REA borrowers' plant with trunks over non-quadded cable pairs. This recommendation applies to repeatered and non-repeatered circuits.

2.042 For new construction where the facilities are completely within the REA borrower's territory, they should be D-66 loaded for the entire trunk length. The load spacing and end section requirements are discussed in Paragraphs 3 and 4, respectively. No junction impedance compensator is required where the entire facility is D-66 loaded.

2.043 For new construction where the REA borrower's facilities connect with those of another company, it is desirable that the entire trunk be D-66 loaded for exchange type cables. Where the D-66 loading is used for such applications for the entire facility it results in certain advantages for the companies involved. Some of the advantages for trunk applications are:

(a) Greater ease in meeting transmission objectives.

(b) Improvement in the circuit structural return loss.

(c) Elimination of impedance compensators at the toll center where toll trunks are involved.

(d) Elimination of junction impedance compensators.

(e) Improved circuit frequency response characteristics.

(f) More adaptable to some forms of data transmission or other special services.

(g) Improved crosstalk loss characteristics.

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In addition to the above factors D-66 is compatible with H-88 loading inasmuch as their nominal 1000 cps attenuation and impedance for same gauge cables have been made to be the same by design. Therefore the use of D-66 loading does not introduce new or non-standard impedances in the telephone plant.

2.0431 Requests to connecting companies should be made at the earliest possible date during the ACD stage and all required technical information on D-66 loading requested by the connecting company should be provided.

2.044 For new construction where the REA borrower's facilities connect with those of another company which has existing H-88 loaded exchange type cable, it may not be practical for the connecting company to furnish D-66 loaded cables for its portion so as to meet the REA borrower's D-66 portion. Where the connecting company has so indicated, the resulting facility makeup will consist of D-66 loading for the REA borrower's portion and H-88 loading for the connecting company's portion. In order to minimize the reflection (low return loss at higher voice frequencies) which would exist at the junction of the two loading systems if the two were connected directly, an impedance compensator is required at the junction. The purpose of the junction compensator and how it is applied is further discussed in paragraph 7.0.

2.045 Existing cables which are H-88 loaded and are being extended may utilize D-66 loading for the extension portion. This treatment, however, will not improve the overall circuit due to the more restrictive cutoff characteristics of the existing H-88 loading, which will be controlling. Where, nevertheless, H-88 circuits are being extended with D-66 a junction compensator as discussed in paragraph 7.0 will be required.

2.046 From the transmission standpoint it is desirable to load additional circuits on a D-66 loading basis in a cable which contains H-88 loaded working cable pairs under the same sheath. However, this may not be attractive from the standpoint of having two different coil locations and two different values of loading coil inductance. The decision, therefore, whether the additions in the same cable sheath

should be D-66 loaded should depend on such factors as:

(a) Whether normal or special transmission objectives can be met by the continuation of the existing type of loading.

(b) Availability of suitable pole, ready-access case or pedestal locations for 66 mh loading coil placement.

(c) Maintenance considerations.

(d) Other factors.

2.047 It is not generally recommended that H-88 working trunk routes which are H-88 loaded in their entirety be changed out to D-66 loading. In applications, however, where transmission objectives are not being met, or where it is necessary to meet special transmission objectives and where loading coil locations are or can be economically made available the use of D-66 loading should be considered. In situations where design changes are proposed affecting the entire system in a major way consideration should be given also to the feasibility of converting to D-66 loading.

2.048 As discussed in the above paragraphs the recommended loading system for REA borrowers' plant is D-66 for new construction and also for extensions or additions to existing plant which is H-88 loaded, where applicable. The D-66 loading will be adequate for all applications normally found in REA borrowers' plant. For this reason and also from the standpoints of plant flexibility and simplicity it is desirable to keep the number of loading systems to a minimum. Use should be made of other types of loading systems when:

(a) Normal transmission requirements cannot be met by the use of D-66 loading.

(b) Special applications where the use of D-66 loading is not suitable.

(c) Circumstances where existing situations may pose maintenance or other special problems.

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3. LOAD SPACING REQUIREMENTS

3.01 As discussed in paragraph 1.03 the increasing application of electronic instrumentalities to voice frequency trunk plant as well as its successful operation requires that close attention be given to the design, staking and construction methods to obtain uniform loading spacing. Because of the necessity, however, of dealing with practical plant considerations precise loading spacings are not usually attainable. The paragraphs below discuss the extent of the loading spacing deviations which are permissible and also the type of deviations which are least objectionable from the transmission standpoint.

3.02 Loading spacing irregularities in trunk cables can be generally divided into two categories:

(a) The amount by which the average of all full loading sections depart from the standard spacing.

(b) The amount by which each full section length departs from the arithmetic average computed for all full sections.

Paragraphs 3.021 and 3.022 below discuss the specific effect which these deviations have on transmission.

3.021 Maintaining the average spacing close to the standard spacing (Paragraph 3.02 a) minimizes the chance of departure from standard attenuation, impedance characteristics and cutoff frequency. In addition when the different cable pairs in the same trunk group are also uniform in their capacitance characteristics this also results in uniform attenuation, impedance and cutoff frequency for all the circuits which is highly desirable. The reasons for maintaining the average spacing close to the standard are:

(a) To keep the measured losses close to the expected losses. For example, this is important during acceptance testing of plant and on a routine basis thereafter.

(b) To avoid special engineering of voice frequency repeaters which use standard network configurations.

(c) To avoid transmission contrasts between circuits in the same trunk group.

When the average spacing departs from the standard spacing, the structural return loss is also affected in addition to the factors discussed above. The amount of this impairment depends solely on the nominal frequency cutoff characteristics of the loading system in question. The lower the cutoff frequency of the loading system the greater will be the impairment (lower structural return loss). In a loading system such as H-88 this impairment is considerable, whereas in the D-66 loading system it is of less practical importance due to its naturally higher cutoff frequency.

3.022 Maintaining the individual sections close to the average spacing (Paragraph 3.02 b) reduces the amount of impedance irregularities which unequal sections introduce and results in good structural return losses. Since this item affects the structural return loss in a major way all efforts should be made to achieve uniform spacing to the greatest extent possible. To illustrate, consider a loaded trunk cable (A) whose average spacing length exceeds the standard spacing by 2% and in which, in addition, all individual sections are equal in their lengths. A cable having its loading points thus spaced will have substantially <u>better</u> structural return loss characteristics (actually the structural return loss theoretically will be <u>infinite</u>) than a loaded cable (B) where the average spacing length <u>is</u> the standard spacing but with individual sections longer and shorter than the average.

3.03 In summary, controlling the average spacing so it is close to the standard spacing results in attenuation, impedance and cutoff frequency uniformity, while controlling the individual spacing so it is close to the average spacing results in good structural return loss. <u>However, it is not as important to adhere to standard spacing with D-66 loading as with H-88 loading. Therefore, with D-66 the average spacing may deviate from the standard spacing to the extent permitted in Paragraph 3.041 and the main effort to improve structural return loss should be in keeping the difference of the individual spacings from their average spacing to a value as low as practicable.</u>

3.031 Examples 1 to 4 which are given in this section illustrate the procedure used for computing loading spacing

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deviations. A short analysis which is presented with each example on the relative importance of the type of spacing deviation in question will be found helpful in complementing the discussion of Paragraphs 3.02 and 3.03 above.

3.032 Where capacitance building-out is used to build out loading sections to normal the computation of the spacing deviation discussed in Paragraphs 3.04 and 3.05 below should include the equivalent of the amount of CBO used. The procedure for doing this is shown in Illustrative Example No. 6.

3.04 Loading Spacing Requirements - R.M.S. Method

3.041 The deviation of the average spacing from the standard spacing should be within ± 3%.

3.042 The R.M.S. value of all the deviations of the individual spacing lengths from the average spacing should not be more than 2%.

3.043 The loading spacing deviations outlined in Paragraph 3.042 above using the R.M.S. method of computation is not at this time a requirement. It is nevertheless recommended as an objective. From the transmission standpoint, control of spacing deviations on an R.M.S. basis is highly desirable as it results in the best possible utilization of the transmission capability of the loading system. It should also be noted that control limits on individual sections are not necessary by this method, due to the self-protecting characteristics of the method on maximum individual deviations.

3.044 Where it is possible to use the R.M.S. method of Paragraph 3.042 the computations should be made in accordance with the procedure shown in the Illustrative Examples 1 to 4 herein.

3.05 Loading Spacing Requirements - Arithmetic Method

3.051 Where the application of the R.M.S. method for determining spacing deviation requirements is not practical due to staking and/or construction or other local factors the method discussed below is considered acceptable.

3.052 The deviation of the average spacing from the standard spacing should be within ± 3%.

3.053 The average of the differences, with signs disregarded, between the individual spacings and the average spacing should be within 2.0%.

3.054 The deviation of the length of the longest individual sections from the average spacing should be within ± 3%.

3.055 Procedures for computing the above deviations when it becomes necessary to use the arithmetic method of this paragraph are shown in the Illustrative Examples 5 and 6.

4. END SECTION REQUIREMENTS

4.01 The objective for office end section length is one-half the length (0.5) of the normal full section. In cases where it is not practical to meet this objective, an end section length within 0.4 to 0.6 can be considered. The choice of the 0.4 length is preferable to the 0.6 end section. The published transmission information contained herein on loaded cables assumes 0.5 end sections.

4.02 The "end section" in loaded trunk cables refers to the length of cable between the central office and the first loading coil, including any cable in the central office leading to the main as well as intermediate distributing frame if existing. It is, however, the amount of capacitance associated with the end section which to a large extent determines, for a given type of loading, the degree of impedance variation across the voice frequency range. This variation is significant for different length end sections. REA TE & CM-444, Issue No. 2, Figure 2, illustrates the effect which the length of an end section has on impedance at various frequencies. In REA borrowers' projects, end section "length" and "capacitance" become synonymous since the same nominal capacitance cable is used for the entire trunk and since the wiring capacitance associated with the local office is not normally significant. For class four offices (toll centers) in REA borrowers' projects or for those of connecting companies the total end section should be considered. The total end section includes not only the physical length of the cable from the first loading point to the central office mainframe but any intervening cable inside the office up to the point of access to the switching equipment.

5. STAKING AND CONSTRUCTION CONSIDERATIONS

5.01 To make possible the realization of the end section objectives outlined in Paragraph 4.02 above, the staking of the plant

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should start from each of the offices involved and proceed in the direction of the opposite office to the junction point. The resulting loading section, at the junction point, which in most instances will be shorter than the normal full section should be built-out to a full section by the use of building-out capacitors which are discussed in Paragraph 6.0. It is not necessary that the junction point (building-out point) be the geographical center between the two offices in question. From the standpoint of repeater application, it is preferable that the built-out section be as far away electrically as practicable from the repeater locations. Example 13 is illustrative of the building-out procedures used for new construction at the junction point.

5.012 It is recommended that at no time the plant be staked and/or constructed in a manner whose purpose is to eliminate the building-out capacitors at the junction, when doing this upsets the regularity of the load spacing which is possible when using building-out capacitors.

5.02 Where more than two offices are involved the procedures for staking are the same as those of Paragraph 5.01 by considering the trunk groups between offices separately. In cases where a portion of the cable facility trunk route is provided by a connecting company, staking should commence from the borrower's central office and proceed toward the boundary point. Example 14 is illustrative of the building-out procedures used for new construction at the junction point.

5.03 The requirements for loading subscriber loops are different from those for loading trunks and are outlined in REA TE & CM-430 "Subscriber Line Loading." In situations where both trunk and subscriber circuits are contained in the same cable sheath for a distance from the central office the plant should be staked to meet the applicable trunk spacing requirements, up to the point where they separate.

5.04 Normally, the construction of aerial cable plant should follow the staking sheet instructions fairly closely and the spacing of loading coils can be relatively precise. However, the lengths of buried cable during placement can vary substantially from those shown on the staking sheets. Additional footage of buried cable may be required to plow around culverts, install aerial inserts, etc., all of which will affect the location of the terminal housings planned for loading coils. For this reason, buried cable plant should be constructed from the central office out toward the extremities of the lead. This is especially important for loaded trunk circuits between two offices, in which case the cable should be installed starting at each office and proceeding toward the other. Construction of these leads should not commence until all of the material is on hand to permit the plowing of cable in the

proper sequence. Plowing the cable in the proper sequence and using the sequential marking on the outside of the cable jacket is the most effective way to insure that the loading coils will be accurately spaced.

6. CAPACITANCE BUILDING-OUT (CBO) PROCEDURES

6.01 Capacitance building-out (referred to as CBO) as applied to loaded trunk cables offers a means of improving the transmission irregularities resulting from loading sections which depart from standard lengths. This may come about from abnormally short or long loading sections in comparison to standard. In new construction capacitance building-out will normally be necessary at the junction point in order to meet the end section objectives of Paragraph 4.01 and using the staking procedures of Paragraphs 5.01 and 5.02 above for making this possible.

6.02 Building-out procedures are particularly useful in applications involving existing loaded cable plant. Properly engineered new plant should not require their use, since building-out is essentially corrective in nature, and it is not a recommended practice when laying out the design of new systems. Correct staking and construction practices should be followed, thus entirely eliminating the need for building-out in all loading sections, except at the junction point as discussed in Paragraphs 5.01 and 5.02 and shown in Illustrative Examples 13, 14 and 15.

6.021 Another exception to the above procedure involves new plant in special applications such as when joining two dissimilar loading systems. This special case is described in Paragraph 8.

6.022 The method by which the attenuation of a loaded trunk cable using CBO is computed is discussed in Paragraph 9.023. The method for computing the spacing deviation when using CBO has been discussed in Paragraph 3.032.

6.03 Individual loading sections in existing cables having less than the standard length may be built-out by:

(a) Bridging capacitors (CBO) (without the need of opening up the cable pair).

(b) Bridging stub cable of the proper length.

(c) Series insertion of additional building-out cable (cable is physically opened and additional building-out cable inserted).

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The use of building out capacitors of item (a) is usually the most economical procedure. Cases may arise, however, in which the series insertion of building-out cable of item (c) would provide a better solution, especially if the conductor involved is 24 gauge or finer in which case the resistance component must be also accounted for, and/or where the length of cable to be built-out is significant and where the particular application requires this added improvement on return loss. An illustration of the treatment of short sections with CBO and the method used to compute the amount required is shown in Illustrative Example 16.

6.04 Individual loading sections in existing plant which are longer than the standard length require, in addition, the use of a loading coil. This loading coil inserted in the section in question at a standard distance from its adjacent loading coil results in a standard loading section. The remaining short loading section is then treated as described in Paragraph 6.03. An example illustrative of the treatment of a long section with CBO and the method used to compute the amount required is shown in Illustrative Example 16.

6.05 End sections in existing plant which are shorter than normal may be built-out to their required value with CBO located at the office. Illustrative Example 16 shows how this is accomplished. End sections in existing plant which are longer than normal may be built-out to their required value by a loading coil and CBO treatment located at the office. Illustrative Example 16 shows how this is accomplished.

6.06 Building-out capacitors may be installed for both new or existing plant at loading coil locations. When installing the building-out capacitors at such loading coil terminal locations, it is imperative that steps be taken during installation to insure that the building-out capacitors are located on the correct side of the loading coil of the loading section which they will build-out. A good method for insuring this is by making actual continuity measurements with a d-c ohmmeter at the point of installation to the central office, rather than relying on cable directions, cable color markings or other such physical markings. If this is not done, the possibility exists that the building-out capacitors may be connected to the wrong loading section which will augment the irregularities and compound the difficulties. It will be found that designating the location for building-out to be consistent on either the office side of the loading coil or its field side for the entire route of the trunk, but not both, will reduce the possibility of errors.

6.061 From the transmission standpoint, the building-out capacitors can be installed at any point in the irregular section which they build-out. An installation point which does not entail the risks outlined in Paragraph 6.06 is to locate the building-out capacitors at a pedestal or pole where no loading coils are present.

6.07 When using capacitance building-out techniques for the purpose of treating the situations outlined above, the capacitors should be specified as per REA PE-30 Specification,*latest issue, thus assuring the required transmission, protection and physical construction performance.

7. THE D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR AND APPLICATIONS

7.01 The device used to match the impedance of the H-88 loading system to that of the D-66 loading system when it is inserted at a point of interconnection (junction) of the two loading systems is termed a "D-66/H-88 junction impedance compensator," or simply "junction compensator."

7.02 The H-88 and D-66 loaded cables have, by design, the same nominal 1000 cps impedance, but as the cutoff frequency of the H-88 loaded cable is approached the impedances of the H-88 loaded trunk facilities increase in magnitude more rapidly than do the impedances of the D-66 loaded cables. Therefore, at frequencies higher than approximately 2500 cps the impedance match between the D-66 and H-88 loaded cable facilities becomes progressively poorer if the two systems are directly interconnected. Operation of voice frequency repeaters may be expected to be impaired due to the resulting poor return loss at the point of such direct interconnection. To obtain adequate return losses at these higher frequencies, it is necessary that the rising impedance of the H-88 be modified to match the flatter impedance of the D-66. The device which makes possible this matching, thereby improving the return loss, is the junction compensator.

7.03 The junction compensator consists of two capacitors in shunt with the tip and ring conductors of the cable pair, an intervening loading coil and two additional capacitors, each shunting one winding of the loading coil. For purposes of differentiation only, the former type capacitors are termed "shunt"

* PE-30 Specification, Building-Out Capacitors

while the latter are termed "series." The shunt capacitors each build-out the D-66 and H-88 natural cable end sections, respectively, to 0.8. This results in a 3600' effective end section for the D-66 and 4800' for the H-88 loading system. The characteristic impedances of both D-66 and H-88 loaded cables at 0.8 end-sections have nearly constant and approximately equal resistive components and negative reactive components non-linear with frequency. Since the desired result is to annul the non-linear negative reactances, the positive linear reactance of a simple loading coil in the compensator is not sufficient to annul the total of the negative reactances. Addition of the "series" capacitors to the loading coil helps in reducing this reactance disparity and the impedances of the D-66 and H-88 loaded systems become better matched.

7.04 The component makeup of the D-66/H-88 junction impedance compensator is shown in Figure 1. It should be noted that the loading coil and series capacitor components (capacitors C_3 and C_4 in Figure 1) are somewhat different for 19 and 22 gauge cables. The shunt or building-out capacitors, however, (capacitors C_1 and C_2 in Figure 1) are the same for either 19 or 22 gauge, since their value depends solely on the length of the cable at the end section. One or both shunt capacitors may be omitted if the natural cable end section on one or both sides of the compensator is 0.8 of its respective full section.

7.041 Where mixed gauges such as 19 and 22 gauge are used at the junction point, the configuration of the junction compensator should be computed for the gauge having the greater 1000 cps loss.

7.05 Illustrative examples pertaining to the application layouts of the junction compensator for various D-66 and H-88 natural end sections are shown in Illustrative Examples 17 to 20. It should be noted that it is not always necessary to place the junction compensator at the point where the D-66 and H-88 cable meet (boundary). From the transmission standpoint, the junction compensator may be physically located at any point within the cable section between the last H-88 and D-66 loading points, which results in reduction in the capacitance of the shunt capacitors in the compensator or in their partial or total elimination.

7.06 Junction compensators should be installed on both repeatered and non-repeatered trunk plant. When ordering the compensators, a

sufficient number of compensator units should be specified for spares as part of the normal circuit requirements.

7.07 The D-66/H-88 junction impedance compensators and all application examples shown herein require the use of exchange type cables for both the connecting company and the REA borrowers' portions. It is the exchange type cable which makes interconnection of D-66 and H-88 loaded cables possible and further, for the reason discussed in Paragraph 7.03, requires the use of the impedance compensator. Where the connecting company provides 19 gauge H-88 loaded cable facilities using low capacitance cable, it is not possible for the REA borrower to use D-66 for connecting to it. In this situation the REA borrowers' portion must consist of D-88 loading. This special case is discussed in Paragraph 8.0.

7.08 To insure proper voice frequency repeater operation, it is imperative that the following steps be taken during the engineering, construction and installation of the junction compensator:

(a) Compute the building-out capacitance required (capacitors C_1 and C_2 in the compensator) only when the lengths of the natural D-66 and H-88 end sections at the junction are firmly known. Changes, if any, in the end sections due to re-staking, re-location or other factors which entail a change in shunt capacitors C_1 and C_2 should also be reflected in the REA PE-31 Specification,* latest issue.

(b) Ascertain through the color code of the completed assembly unit that it is spliced correctly, that is, the D-66 side of the unit is connected to the D-66 portion of the trunk and the H-88 side is connected to the H-88 portion of the trunk. A reversed compensator may adversely affect the performance of voice frequency repeaters operating over the circuit in question.

7.09 To assure proper compensator performance, the units should be ordered in accordance with REA Specification PE-31, latest issue, which covers all pertinent transmission, protection and physical characteristics. External protection for the compensator is not required.

*REA Specification PE-31, D66-H88 Junction Impedance Compensators

8. SPECIAL LOADING APPLICATIONS

8.01 Circumstances may arise in trunk applications where it may not be practical to maintain the same type of loading for the entire length of the trunk. This may come about as a result of the connecting company providing 19 gauge low capacitance cable, either paired or quadded and H-88 loading for its portion of the trunk route. In order to maintain the same mutual capacitance between loading points in the entire trunk, two approaches are technically possible:

(a) For the REA borrower to also provide low capacitance cable for his portion of the trunk so that the entire trunk is H-88 loaded on a low capacitance cable basis.

(b) For the REA borrower to provide exchange type cable and 88 mh loading coils for his portion of the trunk. Since the desired objective is to maintain the same capacitance between loading coils in the entire trunk, obviously the spacing between loading coils for the borrower's portion has to be shortened. This spacing is 4500 feet. This portion now becomes loaded every 4500 feet with 88 mh loading coils (D-88). Thus, the H-88 LC portion of trunk is matched to the D-88 HC portion for impedance and repeaters can properly operate over it.

Of the approaches (a) and (b) above, approach (b) is usually preferable for the REA borrower from the cost standpoint.

8.02 At the point of interconnection of H-88 LC and D-88 HC loading systems, the end section of each system must be 0.5; that is, the H-88 LC must have a 3000' end section and the D-88 HC a 2250' making the total full section at a junction 5250'. Where physical or staking considerations result in a junction section which is less than 5250', or greater than 6000', the building out procedures as outlined in Paragraph 6.0 must be used to maintain the total capacitance required for that junction section. Illustrative Example 21 shows how such a special case is handled.

8.021 Low capacitance 22 gauge cable is not manufactured as a standard cable. Therefore, the aspect of interconnection of the two loading systems applies only to 19 gauge cables.

9. PROCEDURE FOR COMPUTING LOADED TRUNK ATTENUATION

9.01 For purposes of transmission computations the attenuation of a loaded trunk cable is normally calculated at 1000 cps and 68°F. Table I provides attenuation information at 1000 cps and 68°F for various types of loading systems and cable gauges for both exchange and low capacitance type of cables for carrying out the required computations. The attenuation of the loaded cable must also include the transmission loss caused by reflections at the junction of facilities having dissimilar 1000 cps impedances and other incidental losses en route, such as the loss of junction impedance compensators. Table II provides the reflection loss information at 1000 cps; the loss of the junction compensator should be computed as discussed in Paragraph 9.022.

9.011 In cases where it becomes necessary to know the attenuation of a loaded trunk cable at frequencies other than 1000 cps, the information in Figures 2 through 5 can be used.

9.02 In general, the attenuation of a circuit consisting of various lengths of facility having conductors of the same or different gauges, with the same or dissimilar capacitance between conductors and having the same type of loading throughout or consisting of two dissimilar loading systems, is obtained by multiplying the applicable db loss per unit length for each type of facility in Table I by the corresponding length (in the same unit of length) of that facility and summing up all individual attenuations and adding to this reflections, losses of junction compensators or other incidental losses en route, where applicable.

9.021 The attenuation information of Table I is based on the mid-section impedance of the loading system for the particular gauge and mutual capacitance shown. Attenuation computations, therefore, involving circuits which consist of mixed gauges, dissimilar loading systems and dissimilar mutual capacitance will be <u>rigorously correct</u> only when computed on the basis that a change of gauge occurs at mid-section only. Due, however, mainly to the complexity in computation which the above procedure would entail in actual loading layouts, it will be sufficient to a first good approximation at 1000 cps to consider each gauge by simply multiplying its applicable db loss per unit length by the actual length, with no regard whether the change of gauge occurs at mid-section.

9.022 In computing the attenuation of a circuit consisting of D-66 and H-88 loading the loss of the D-66/H-88 junction compensator must be included in the computation. This loss, at 1000 cps, should be taken as 0.3 db regardless of the amount of CBO used in the compensator to build out the D-66 and H-88 sides for either 19 or 22 gauge cables.

9.023 As discussed in Paragraphs 6.01 and 6.02 capacitance building-out will be required to build out loading sections which are shorter than normal. The amount of building-out capacitance required will of course vary with the length of the section being built out. For purposes of transmission computations at 1000 cps it will not be necessary to consider the small dissipation loss caused by these capacitors as part of the circuit attenuation but only the amount of physical cable present as discussed in Paragraph 9.021 above. The above simplification in computation procedure is predicated on two conditions:

(a) That no resistance building-out (BOR) is used <u>in</u> the building-out capacitors.

(b) The capacitors are specified in accordance with REA Specification PE-30, which limits the amount of capacitor dissipation permissible.

All illustrative examples shown herein, using building-out capacitors assume <u>no</u> corresponding BOR.

In cases where, for return loss reasons, it becomes necessary to use resistance in addition to the capacitance of the building-out unit, for applications to cables consisting primarily of 24 gauge or finer, the 1000 cps attenuation should be computed to include the amount of capacitance building-out by converting this capacitance to an equivalent length of a physical cable having the same gauge as the section being built out and multiplying this equivalent length by the corresponding db loss per unit length for that gauge in Table I.

9.024 Regarding incidental entrance cables which are loaded, when the length of the loaded portion of the cable is such that the end section exceeds a half section, the length of the cable affected by the loading is multiplied by the applicable db loss per unit length for the gauge and the loading system used and the remainder of the cable is multiplied by the corresponding db loss per unit length for the nonloaded cable. The total loss for this portion of the circuit is obtained by adding together the loaded and nonloaded attenuations.

9.025 In connection with existing trunk plant, need will arise for computing the expected attenuation of trunk circuits consisting of combinations of loaded nonjacketed (older type) and nonloaded multipair shielded cables, loaded former type rural distribution wire and steel or copper-steel open wire conductors. The attenuation of nonloaded cable pairs and open wire conductors will be found in REA TE & CM-406, "Attenuation Data." The attenuation of loaded rural distribution types of cables, both for the former type and the Figure 8 type, is included in Table I herein. The reflection loss information pertaining to all dissimilar facilities, normally to be encountered, is given in Table II herein.

9.03 Examples 7 - 12 will be helpful in illustrating the computation procedures discussed in the above paragraphs.

Illustrative Example 1

To show how to compute the RMS spacing deviation of a D-66 loaded trunk cable, staked and constructed with the spacing shown below:

Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
4365	4365	0	0
Total 26,190			0

Avg. 26,190/6 = 4365'

$$\text{RMS} = \sqrt{\frac{0}{6}} = \text{zero feet}$$

(a) Deviation of Average Spacing from Standard: $\frac{4365 - 4500}{4500} = -3\%$

(b) RMS Deviation from Average Spacing : $\frac{0}{4365} = 0\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met in (a) and (b) above.

Analysis: Since the deviations of the loading spacings from the average spacing are zero (column 3), i.e., all the loading sections are alike, this load spacing will result in practically infinite structural return loss (assuming the cable capacitance also to be equally uniform).

Illustrative Example 2

To show how to compute the RMS spacing deviation of a D-66 loaded trunk cable, staked and constructed with the spacing shown below:

Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
4635	4635	0	0
4635	4635	0	0
4635	4635	0	0
4635	4635	0	0
4635	4635	0	0
4635	4635	0	0
4635	4635	0	0
4635	4635	0	0
Total 37,080			0

Avg. 37,080/8 = 4635'

RMS $= \sqrt{\frac{0}{8}}$ = zero feet

(a) Deviation of Average Spacing from Standard: $\frac{4635 - 4500}{4500} = +3\%$

(b) RMS Deviation from Average Spacing : $\frac{0}{4635} = 0\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met.

Analysis: (a) Since the deviations of the loading spacings from the average spacing are zero (column 3), i.e., all the loading sections are alike, this loading spacing will result in practically infinite structural return loss (assuming the cable capacitance also to be equally uniform).

(b) The spacings in this example and Example 1 will both result in equally good structural return loss. However, the spacing of Example 1 will result in somewhat lower attenuation and higher impedance and slightly higher cutoff frequency, since its average spacing is less than the standards (4500').

Illustrative Example 3

To show how to compute the RMS spacing deviation of a D-66 loaded trunk cable, staked and constructed with the spacing shown below:

Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
4590	4500	+ 90	8100
4464	4500	- 36	1296
4680	4500	+180	32,400
4518	4500	+ 18	324
4410	4500	- 90	8100
4428	4500	- 72	5184
4464	4500	- 36	1296
4572	4500	+ 72	5184
4320	4500	-180	32,400
4536	4500	+ 36	1296
4482	4500	- 18	324
4536	4500	+ 36	1296
Total 54,000			97,200

Avg. $54,000/12 = 4500'$ RMS $= \sqrt{\frac{97,200}{12}} = 90$ feet

(a) Deviation of Average Spacing from Standard: $\frac{4500 - 4500}{4500} = 0\%$

(b) RMS Deviation from Average Spacing : $\frac{90}{4500} = 2\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met in (a) and (b) above.

Analysis: (a) The structural return loss in this example will not be as good as that of either Examples 1 or 2, because the individual loading sections are unequal, i.e., larger or shorter than the average, despite the perfect average spacing (4500').

(b) If only two large deviations of 180' existed, the RMS deviation would have been 73.5' as compared to 90' for all the deviations. The two deviations of 180' and the two deviations of 90' account for 82.2' of the total RMS deviation of 90'. In this example it is, therefore, particularly desirable to reduce the large deviations.

(c) If there were only two deviations of +110' and -110', the RMS deviation would be only about 1%.

Illustrative Example 4

To show how to compute the effect of one large deviation in loading spacing on the RMS deviation. The remaining deviations are assumed to be small in comparison with the one large deviation:

Solution: The one large spacing deviation which can be tolerated on an RMS basis is given by the following expression to a good approximation:

$$D = RMS\sqrt{n}$$

Where "D" is the one large load spacing deviation in feet,
"n" is the number of loading sections, and
RMS is the 2% of 4500 allowable or 90'

As an example, if a loaded trunk cable has 12 loading sections and is aimed at an average spacing of 4450', one large deviation, D, can be tolerated if necessary:

$$D = RMS\sqrt{n} = 90\sqrt{12} = 312'$$

Therefore, the loading section can be: 4450 + 312 = 4762' long.

The following example illustrates the computation method for justifying this 4762'* loading section:

Loading Section Length	Average Spacing	Deviation of Loading Section from Average	Deviation Squared
4451	4478	27	729
4454	4478	24	576
4449	4478	29	841
4461	4478	17	289
4452	4478	26	676
4450	4478	28	784
4762*	4478	284*	80,656
4453	4478	25	625
4451	4478	27	729
4453	4478	25	625
4447	4478	31	961
4453	4478	25	625
Total 53,736			88,116
Avg. 53,736/12 = 4478		$RMS = \sqrt{\frac{88,116}{12}} = 85.7$ feet	

(a) Deviation of Average Spacing from Standard: $\frac{4478 - 4500}{4500} = -0.5\%$

(b) RMS Deviation from Average Spacing : $\frac{85.7}{4478} = 1.9\%$

Conformance to Requirements: The deviation requirements of paragraphs 3.041 and 3.042 are met in (a) and (b) above.

Analysis: (a) If all the individual deviations but one are kept small, it is possible to meet the RMS deviation requirements.

(b) Had this layout been considered on the basis of paragraph 3.05, the large 284' deviation would not meet the requirements of paragraph 3.054 since this paragraph permits a maximum deviation from average spacing of 3% and 3% of 4478' is 134'.

NOTE: IF TWO LARGE BUT EQUAL DEVIATIONS ONLY ARE NECESSARY, THE FORMULA BECOMES:

$$D = RMS\sqrt{\frac{n}{2}}$$

FOR THREE EQUAL DEVIATIONS:

$$D = RMS\sqrt{\frac{n}{3}}$$

Illustrative Example 5 To show how to compute the spacing deviation using the arithmetic method of a D-66 loaded trunk cable having the load spacing shown below.

	Loading Section Length	Average Spacing	Deviation of Loading Section from Average
	4635	4501	134
	4511	4501	10
	4374	4501	127
	4590	4501	89
	4365	4501	136
	4410	4501	91
	4613	4501	112
	4626	4501	125
	4522	4501	21
	4500	4501	1
	4387	4501	114
	4478	4501	23
Total	54,011		983

Avg. Spacing: 54,011/12 = 4501' Avg. Dev.: 983/12 = 82'

(a) Deviation of Avg. Spacing from Standard: $\frac{4501 - 4500}{4500} = 0.02\%$
(Paragraph 3.052)

(b) Deviation of Avg. of Differences from Avg. Spacing: $\frac{82}{4501} = 1.8\%$
(Paragraph 3.053)

(c) Maximum Individual Spacing Dev. from Avg. Spacing: $\frac{4365 - 4501}{4501} = -3\%$
(Paragraph 3.054)

Illustrative Example 6 To show how to compute the spacing deviation on an existing H-88 loaded trunk cable using the arithmetic method.

(Note: In this particular layout, the length of loading sections Nos. 7 and 22 are 1305' and 4251', respectively. Building-out capacitors of 0.073 and 0.025 microfarads have, however, been used at sections Nos. 7 and 22, respectively, to build out sections to normal. In the computations below, the equivalent length of the CBO is included as part of the section length as discussed in Paragraph 3.032.)

Loading Section Number	Loading Section Length	Average Spacing	Deviation of Loading Section from Average
1	6012	6014	2
2	5904	"	110
3	5835	"	179
4	6236	"	222
5	5989	"	25
6	5991	"	23
7	1305 + .073 µf = 5949	"	65
8	5996	"	18
9	6033	"	19
10	5967	"	47
11	6000	"	14
12	6296	"	282
13	5996	"	18
14	6000	"	14
15	6000	"	14
16	6069	"	55
17	6018	"	4
18	6033	"	19
19	6105	"	91
20	6048	"	34
21	5996	"	18
22	4251 + .025 µf = 5841	"	173
Total	132,314		1446

Avg. Spacing: 132,314/22 = 6014' Avg. Dev.: 1446/22 = 22'

(a) Deviation of Avg. Spacing from Standard: $\frac{6014 - 6000}{6000} = 0.2\%$
(Paragraph 3.052)

(b) Deviation of Avg. of Differences from Avg. Spacing: $\frac{66}{6014} = 1.1\%$
(Paragraph 3.053)

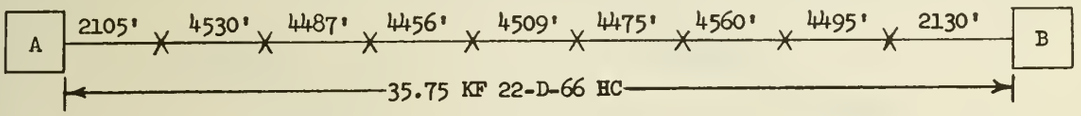
(c) Maximum Individual Spacing Dev. from Avg. Spacing: $\frac{6296 - 6014}{6014} = 4.7\%$
(Paragraph 3.054)

08.614:

BOOK STACKS

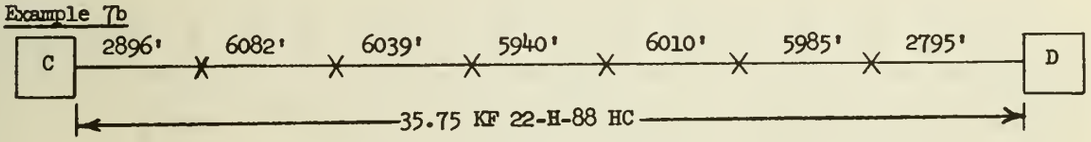
Illustrative Example 7 To show how to compute the attenuation of a loaded trunk cable similar to the ones shown below, at 1000 cps and 68°F.

Example 7a



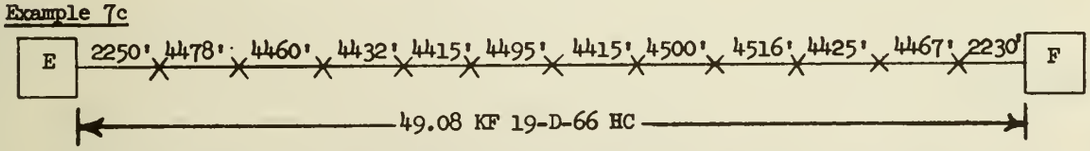
Procedure	Answer
35.75 KF x 0.15 db/KF	5.36 db

Example 7b



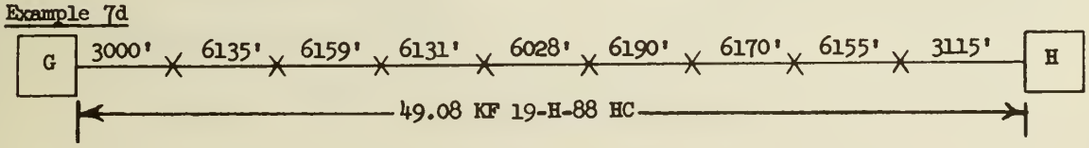
35.75 KF x 0.15 db/KF	5.36 db

Example 7c



49.08 KF x 0.081 db/KF	3.98 db

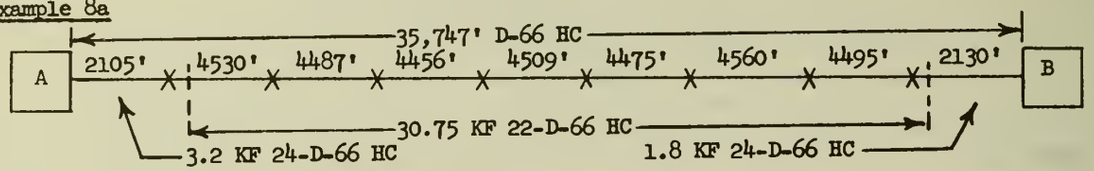
Example 7d



49.08 KF x 0.081 db/KF	3.98 db

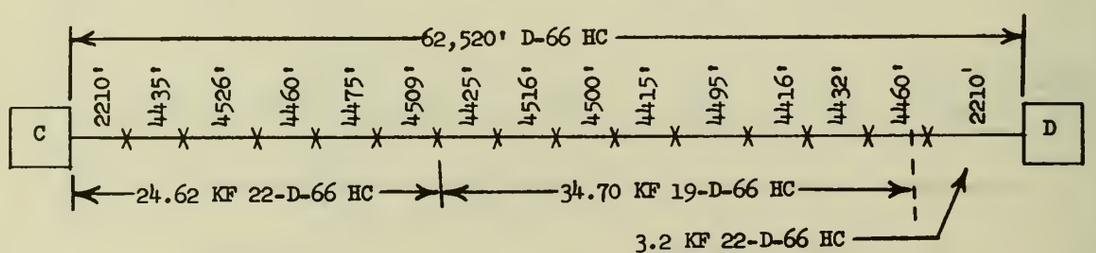
Illustrative Example 8 To show how to compute the attenuation of a loaded trunk cable similar to the ones shown below at 1000 cps and 68°F.

Example 8a



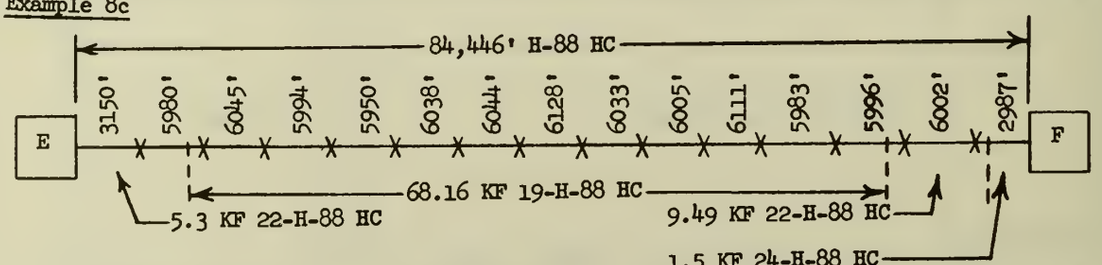
Procedure	Answer
(3.2 + 1.8) x 0.23 + 30.75 x 0.15	5.76 db

Example 8b



(24.62 + 3.2) x 0.15 + 34.70 x 0.081 6.98 db

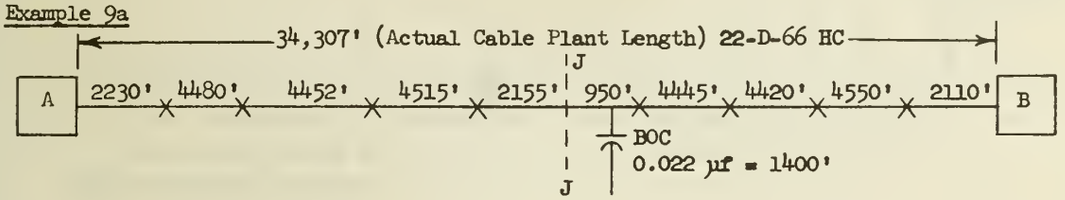
Example 8c



1.5 x 0.23 + (9.49 + 5.3) x 0.15 + 68.16 x 0.081 8.09 db

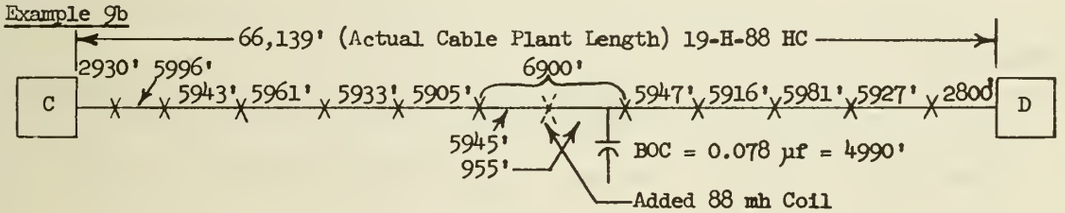
Illustrative Example 9 To show how to compute the attenuation of a loaded trunk cable similar to the ones shown below, at 1000 cps and 68°F.

Example 9a



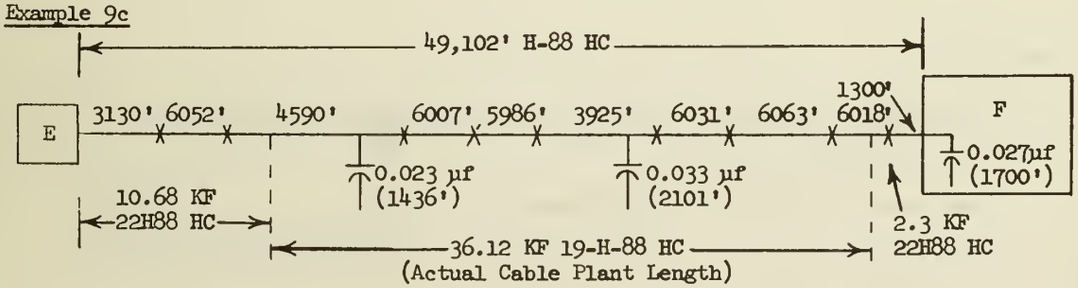
Procedure	Answer
34.31 KF x 0.15 db/KF	5.15 db

Example 9b



66.14 KF x 0.081 db/KF	5.36 db

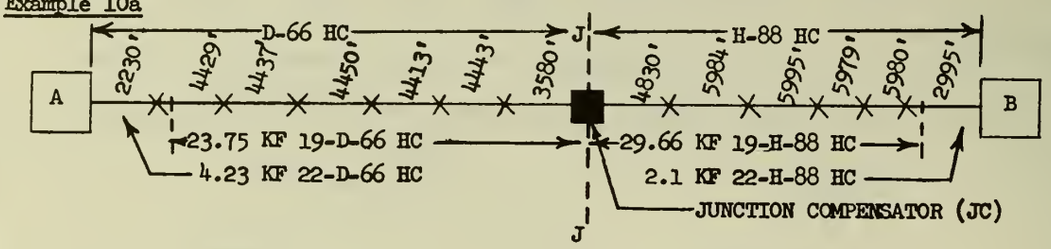
Example 9c



(10.68 + 2.3) x 0.15 + 36.12 x 0.081	4.88 db

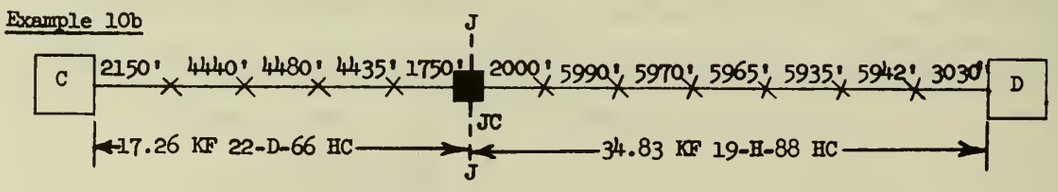
Illustrative Example 10 To show how to compute the attenuation of a loaded trunk cable similar to the one shown below at 1000 cps and 68°F.

Example 10a



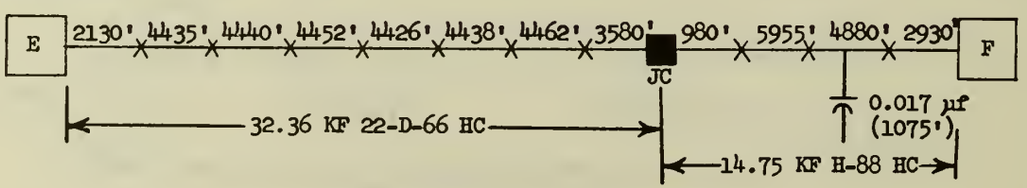
Procedure	Answer
Cable Attenuation + JC Loss (4.23 + 2.1) x 0.15 + (23.75 + 29.66) x 0.081 + 0.3	5.58 db

Example 10b



(17.26 x 0.15) + (34.83 x 0.081) + 0.3	5.71 db

Example 10c



47.11 KF x 0.15 db/KF + 0.3	7.37 db

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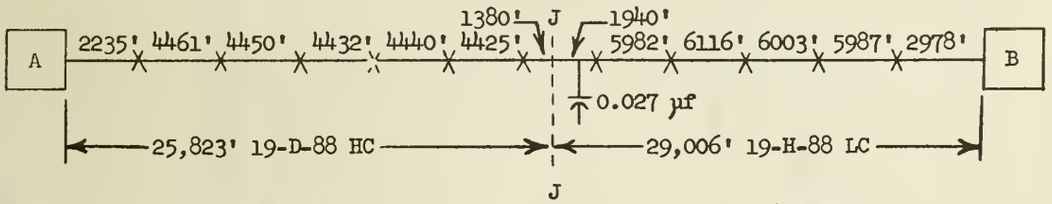
Illustrative Example 11 To show how to compute the attenuation of a loaded trunk cable similar to the one shown below at 1000 cps and 68°F.

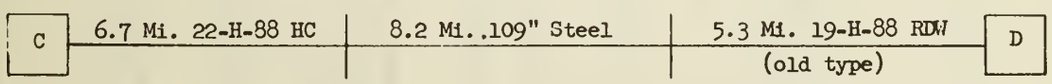


Computation	Answer
54.83 KF x 0.071 db/KF	3.89 db

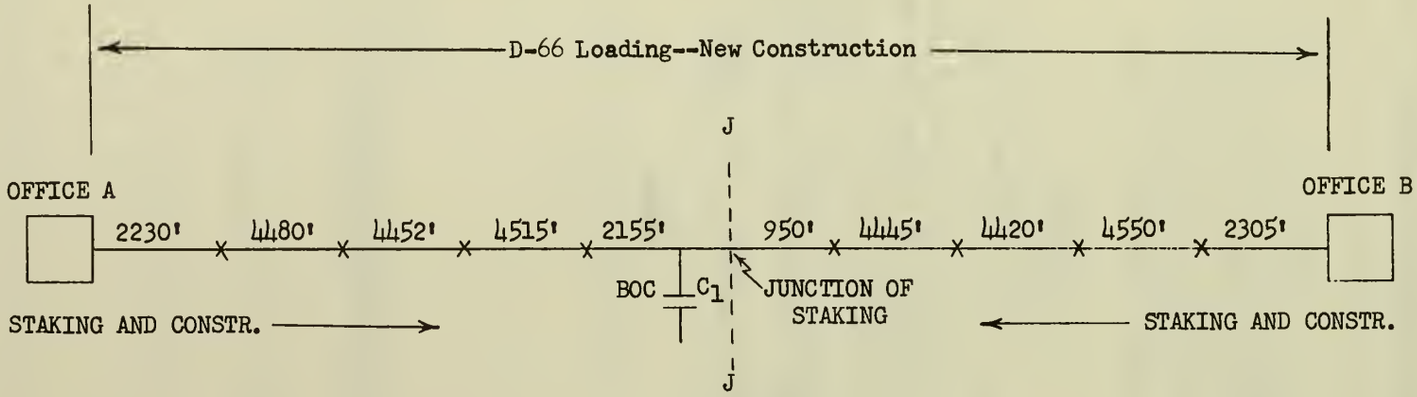
Illustrative Example 12 To show how to compute the attenuation of a loaded trunk cable similar to the one shown below at 1000 cps and 68°F.

Example 12a

Procedure	Answer
Attenuation + Reflection (14.4 x 0.792) + (32.5 x 0.078) + (0.2)	14.13 db



(6.7 x 0.792) + (8.2 x 0.31) + (5.3 x 0.514) + (0) + (0) Reflections	10.57 db



(1) Average full load spacing is:

$$\frac{4480' + 4452' + 4515' + 4445' + 4420' + 4550'}{6} = 4477'$$

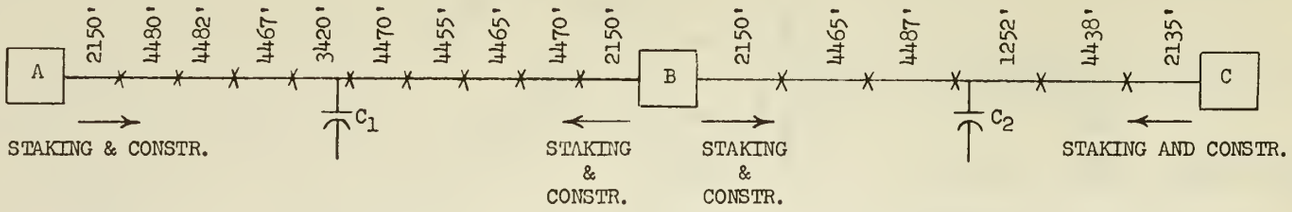
(2) Amount of building-out capacitance required at junction is:

$$\frac{[4477' - (2155' + 950')]}{5280} \times 0.083 = \frac{1372}{5280} \times 0.083 = .022\ \mu f = C_1$$

Therefore, the value of capacitor C_1 is .022 μf and should be ordered in accordance with PE-30.

Notes: 1. All cable PE-22 or PE-23.
2. Both offices in REA borrowers' system.

ILLUSTRATIVE EXAMPLE 13
CBO COMPUTATION FOR NEW CONSTRUCTION AT JUNCTION POINT OF STAKING



OFFICE A - B

Avg. Spacing = (4480' + 4482' + 4467' + 4470' + 4455' + 4465' + 4470')/7 = 4470'

$$C_1 = \frac{4470' - 3420'}{5280'} \times 0.083 = 0.017 \ \mu f \text{ (ORDER PER PE-30)}$$

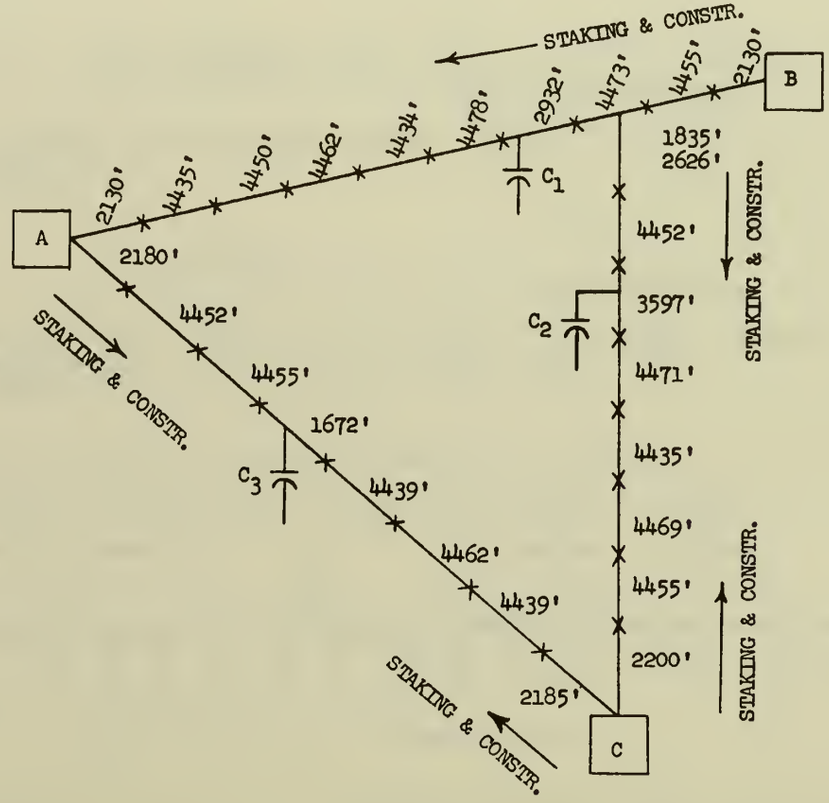
OFFICE B - C

Avg. Spacing = (4465' + 4487' + 4438')/3 = 4463'

$$C_2 = \frac{4463' - 1252'}{5280'} \times 0.083 = 0.051 \ \mu f \text{ (ORDER PER PE-30)}$$

ILLUSTRATIVE EXAMPLE 14

CBO COMPUTATION FOR NEW CONSTRUCTION AT THE JUNCTION POINT



OFFICE A-B

Avg. Spac. = (4435' + 4450' + 4462' + 4434' + 4478' + 4473' + 4455')/7 = 4455'

$C_1 = \frac{4455' - 2932'}{5280'} \times 0.083 = 0.024\mu f$

OFFICE B - C

Avg. Spac. = (4455' + 4461' + 4452' + 4471' + 4435' + 4469' + 4455')/7 = 4457'

$C_2 = \frac{4457' - 3597'}{5280'} \times 0.083 = 0.014\mu f$

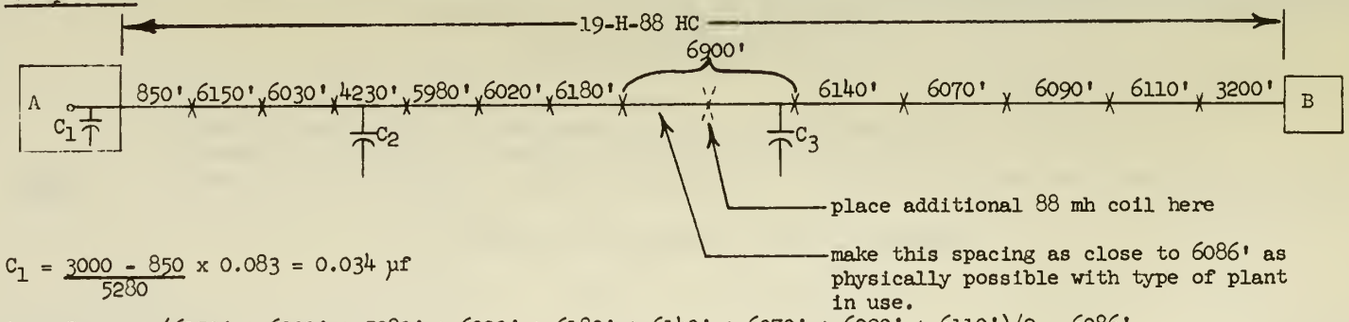
OFFICE A - C

Avg. Spac. = (4452' + 4455' + 4439' + 4462' + 4439')/5 = 4449'

$C_3 = \frac{4449' - 1672'}{5280'} \times 0.083 = 0.044\mu f$

ILLUSTRATIVE EXAMPLE 15
CBO COMPUTATION FOR NEW CONSTRUCTION AT THE JUNCTION POINT

Example 16a



$C_1 = \frac{3000 - 850}{5280} \times 0.083 = 0.034\ \mu f$

Avg. Spac. = (6150' + 6030' + 5980' + 6020' + 6180' + 6140' + 6070' + 6090' + 6110')/9 = 6086'

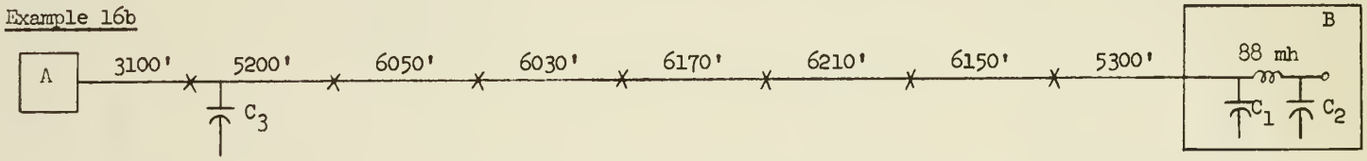
$C_2 = \frac{6086 - 4230}{5280} \times 0.083 = 0.029\ \mu f$

Loading Section No. 7 (Office A) = 6086'

$C_3 = \frac{2\ (6086) - 6900}{5280} \times 0.083 = 0.083\ \mu f$

ORDER ALL BUILDING-OUT CAPACITORS PER REA SPECIFICATION PE-30

Example 16b



Avg. Spac. = (6050 + 6030 + 6170 + 6210 + 6150)/5 = 6122'

$C_3 = \frac{6122 - 5200}{5280} \times 0.083 = 0.015\ \mu f$

Coil—CBO Unit

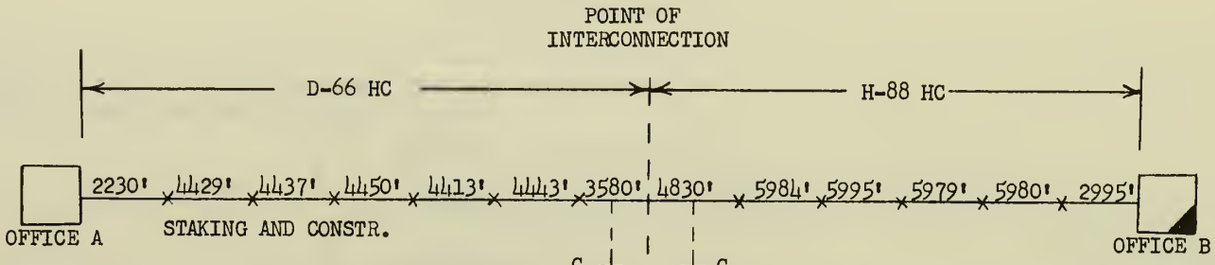
$C_1 = \frac{6122 - 5300}{5280} \times 0.083 = 0.013\ \mu f$

$C_2 = \frac{3000 - 0}{5280} \times 0.083 = 0.047\ \mu f$

a. ORDER C_3 CBO AS PER REA SPECIFICATION PE-30.
b. ORDER COIL-CBO UNIT AS ONE ASSEMBLY UNIT FOR EASE OF MOUNTING.

ILLUSTRATIVE EXAMPLE 16

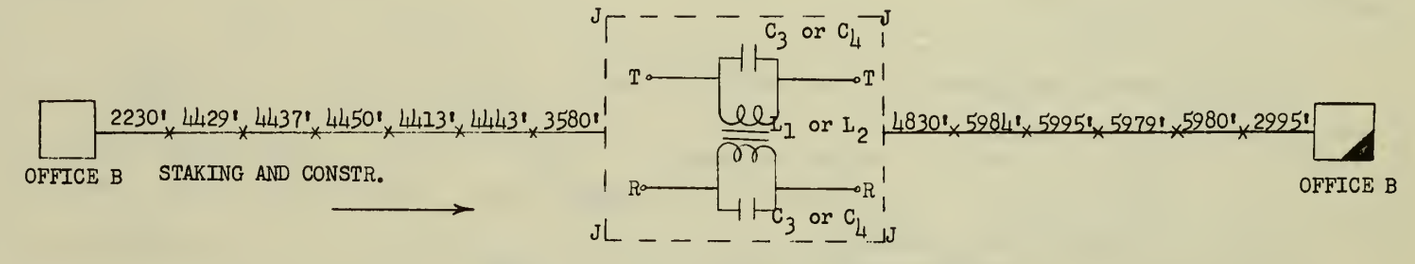
CBO AND COIL COMPUTATIONS FOR EXISTING PLANT



Since the natural D-66 end section is nearly 0.8 (3600') no CBO is required in the junction compensator. Therefore, capacitor $C_1 = 0$.

Since the natural H-88 end section is nearly 0.8 (4800') no CBO is required in the junction compensator. Therefore, capacitor $C_2 = 0$.

A. CABLE LAYOUT UNDER CONSIDERATION



B. RESULTING APPLICATION OF JUNCTION COMPENSATOR

Notes:
1. In Examples 17 to 20, refer to Figure 1 for values of L_1 or L_2 of loading coil inductance and values of capacitance for C_3 or C_4 "series" capacitors in the compensator.
2. "T" and "R" designations in compensator refer to tip and ring conductor identification.
3. Office B is office of the connecting company.

ILLUSTRATIVE EXAMPLE 17
APPLICATION OF THE JUNCTION COMPENSATOR

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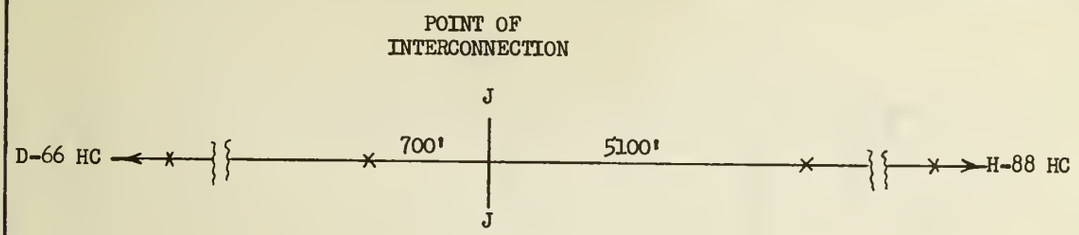
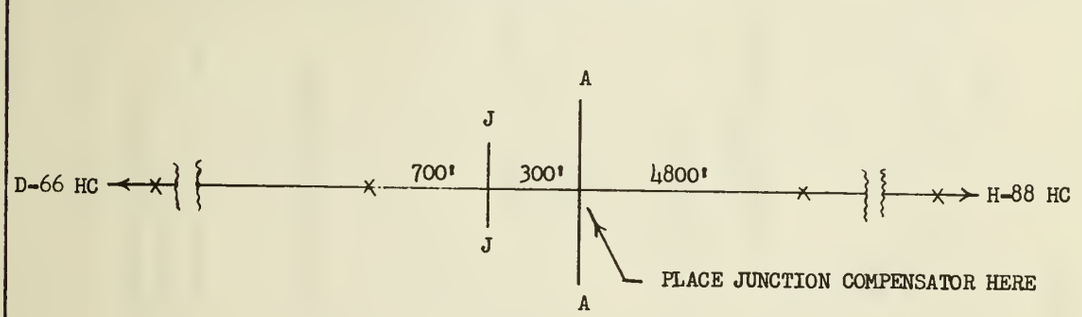
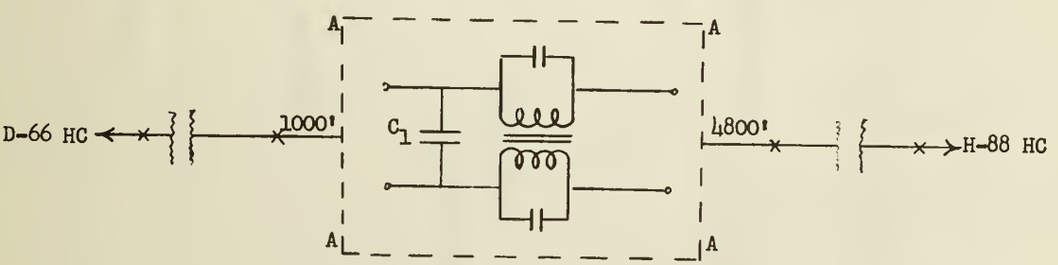


A. CABLE LAYOUT UNDER CONSIDERATION





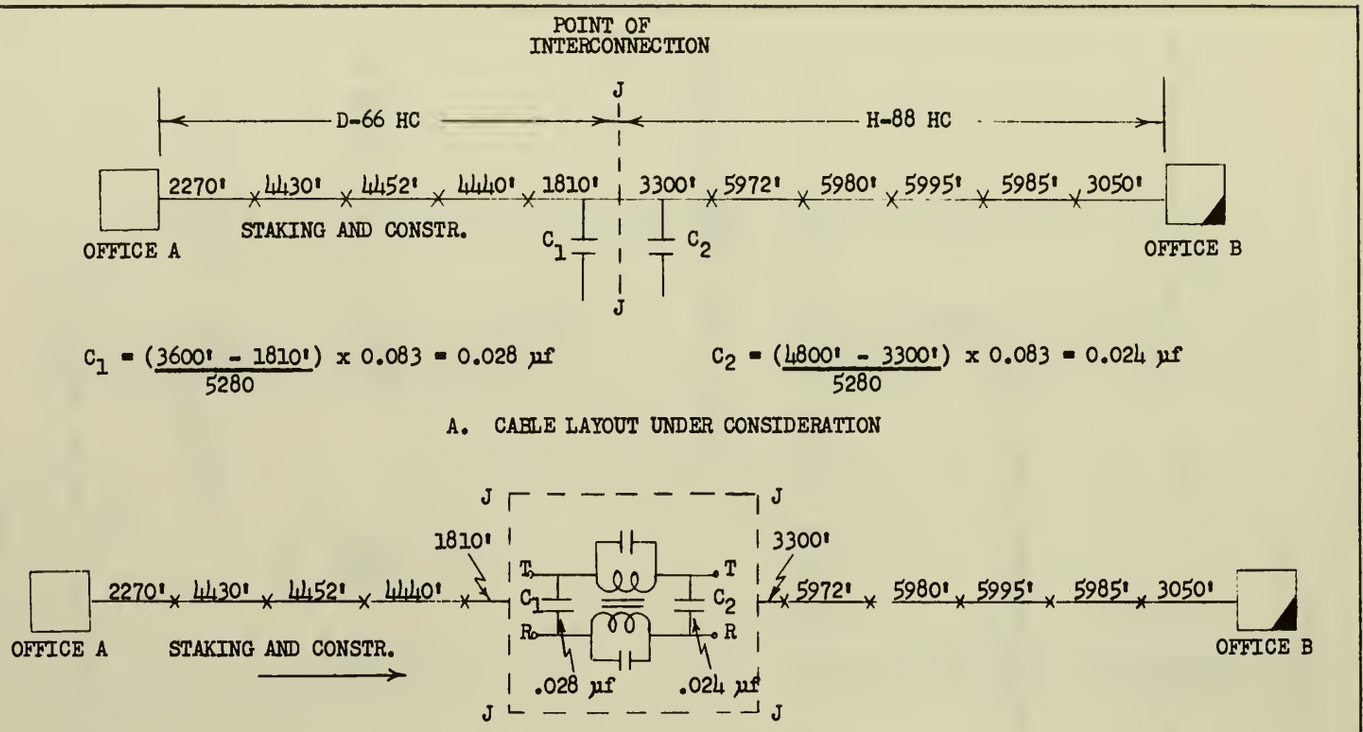
$$C_1 = \frac{(3600' - 1000')}{5280} \times 0.083 = 0.041\ \mu f$$

$$C_2 = 0$$

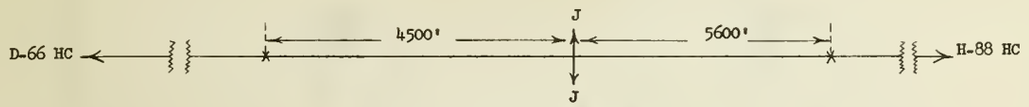
B. RESULTING APPLICATION OF JUNCTION COMPENSATOR

ILLUSTRATIVE EXAMPLE 18

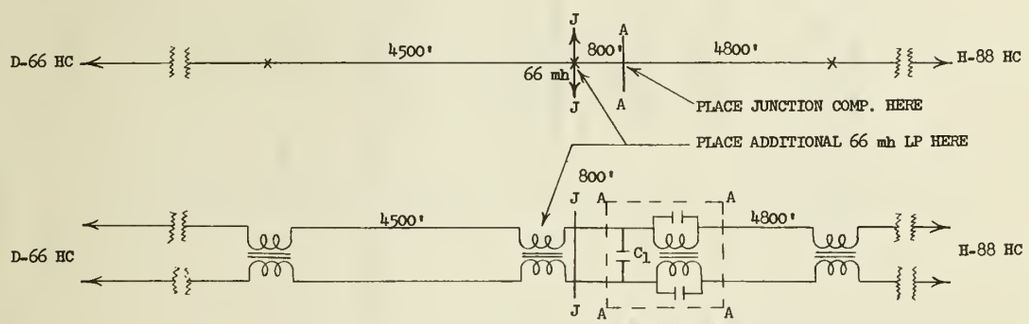
APPLICATION OF THE JUNCTION COMPENSATOR



ILLUSTRATIVE EXAMPLE 19
APPLICATION OF THE JUNCTION COMPENSATOR



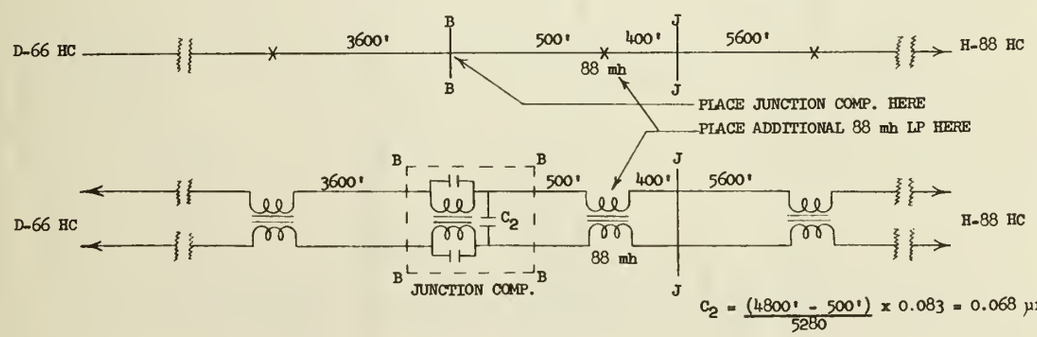
A. CABLE LAYOUT UNDER CONSIDERATION



$C_1 = \frac{(3600' - 800')}{5280} \times 0.083 = 0.044\ \mu f$

$C_2 = 0$

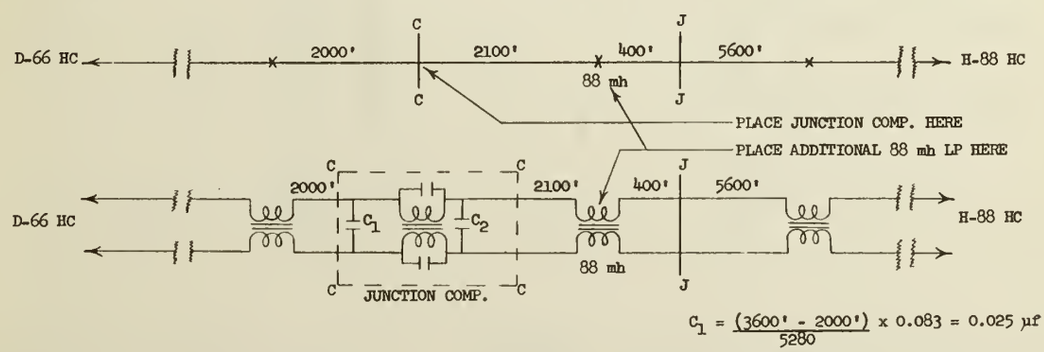
B. ONE POSSIBLE SOLUTION AND RESULTING JUNCTION COMP. CONFIGURATION



$C_2 = \frac{(4800' - 500')}{5280} \times 0.083 = 0.068\ \mu f$

$C_1 = 0$

C. ANOTHER POSSIBLE SOLUTION AND RESULTING JUNCTION COMP. CONFIGURATION

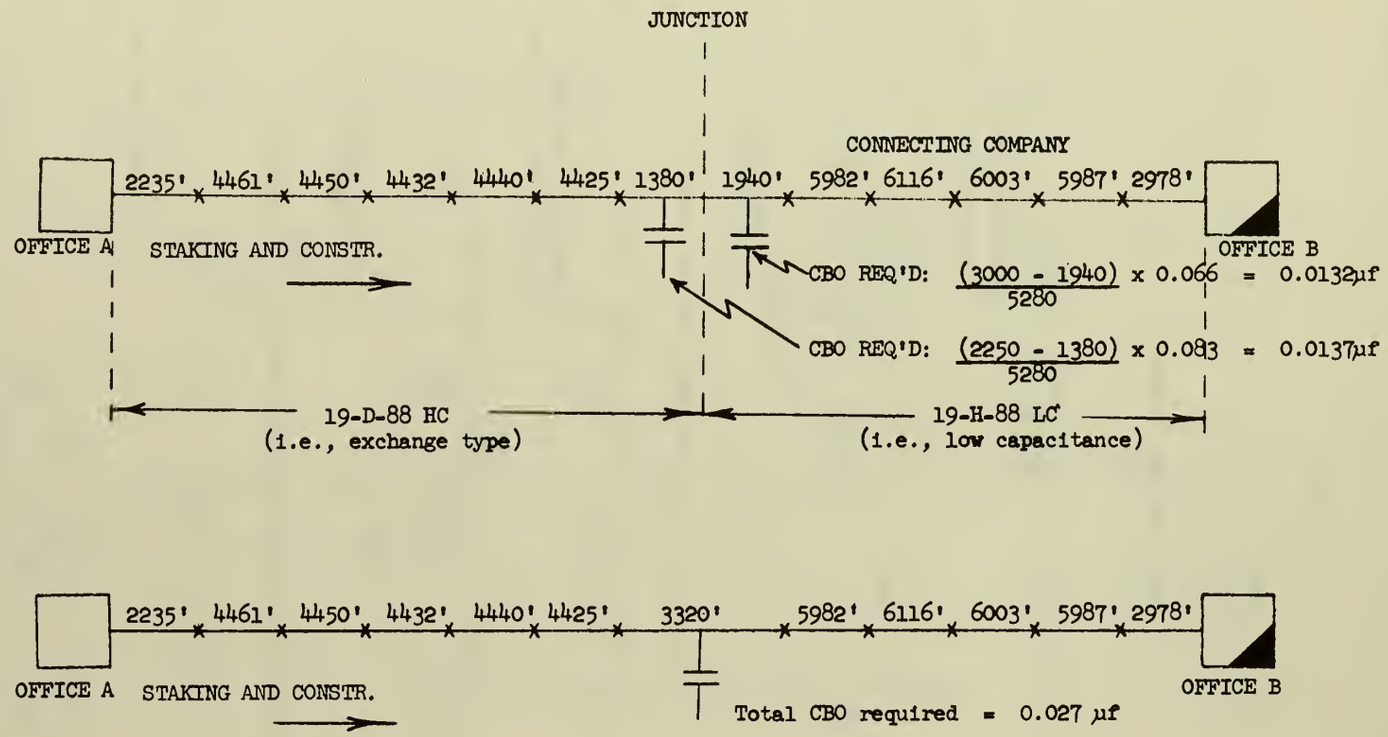


$C_1 = \frac{(3600' - 2000')}{5280} \times 0.083 = 0.025\ \mu f$

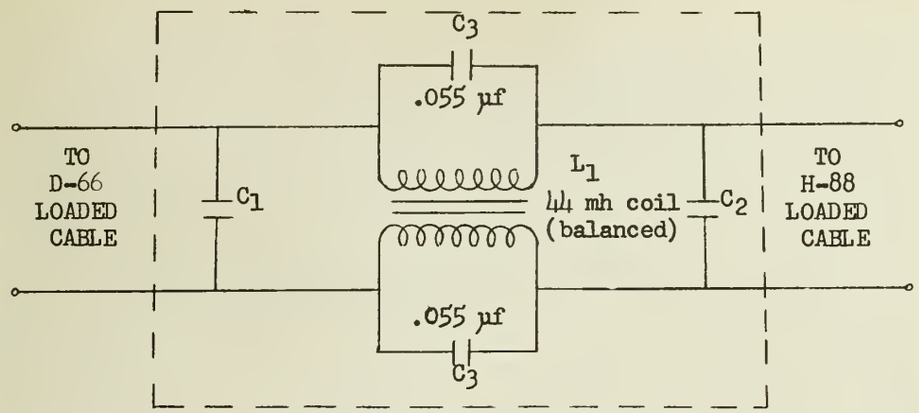
$C_2 = \frac{(4800' - 2100')}{5280} \times 0.083 = 0.042\ \mu f$

D. ANOTHER POSSIBLE SOLUTION AND RESULTING JUNCTION COMP. CONFIGURATION

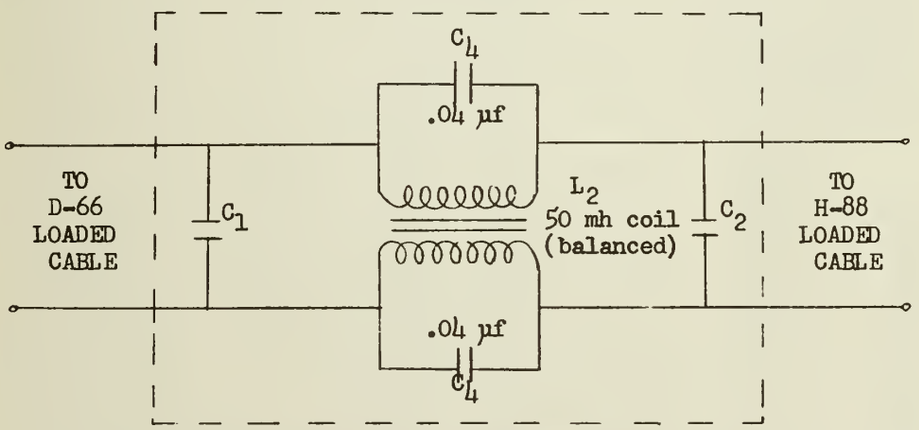
ILLUSTRATIVE EXAMPLE 20
APPLICATION OF THE JUNCTION COMPENSATOR


JUNCTION
CONNECTING COMPANY
2235' 4461' 4450' 4432' 4440' 4425' 1380' 1940' 5982' 6116' 6003' 5987' 2978'
OFFICE A
STAKING AND CONSTR.
OFFICE B
CBO REQ'D: (3000 - 1940) / 5280 x 0.066 = 0.0132µf
CBO REQ'D: (2250 - 1380) / 5280 x 0.083 = 0.0137µf
19-D-88 HC
(i.e., exchange type)
19-H-88 LC
(i.e., low capacitance)
2235' 4461' 4450' 4432' 4440' 4425' 3320' 5982' 6116' 6003' 5987' 2978'
OFFICE A
STAKING AND CONSTR.
OFFICE B
Total CBO required = 0.027 µf

ILLUSTRATIVE EXAMPLE 21
CBO COMPUTATION AT JUNCTION OF 19D-88HC AND 19H-88 LC



A. D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR FOR 22-GAUGE CABLES



B. D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR FOR 19-GAUGE CABLES

NOTES:

1. C_1 = Capacitance required to build D-66 natural end section to .8 of full loading section (3600').

2. C_2 = Capacitance required to build H-88 natural end section to .8 of full loading section (4800').

3. (See Illustrative Examples 17 to 20 for computing capacitance required for shunt capacitors C_1 and C_2.)

4. Order Junction Compensator as per REA Specification PE-31.

FIGURE 1
CONFIGURATION OF THE D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR

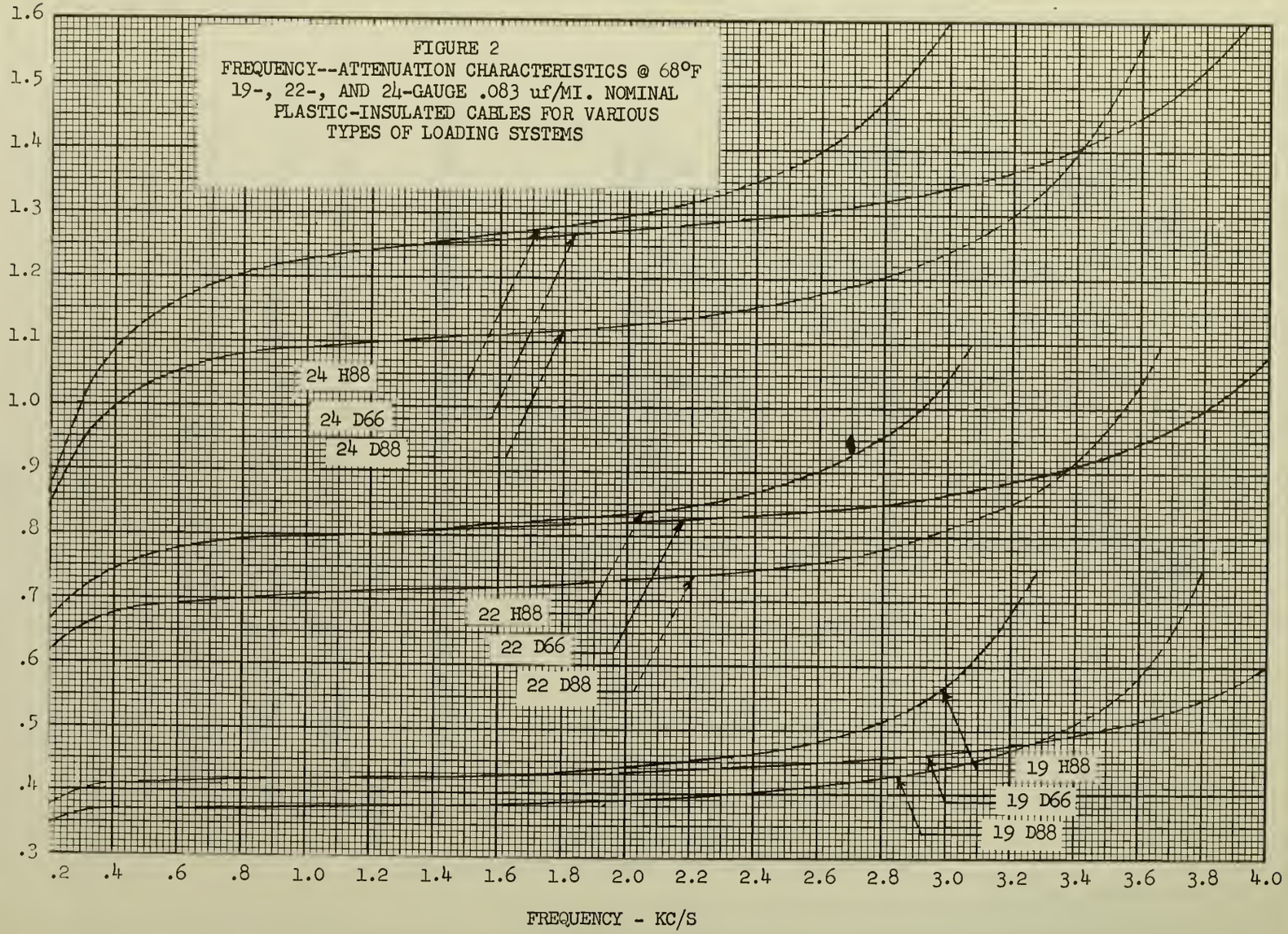


FIGURE 2
FREQUENCY--ATTENUATION CHARACTERISTICS @ 68°F
19-, 22-, AND 24-GAUGE .083 uf/MI. NOMINAL
PLASTIC-INSULATED CABLES FOR VARIOUS
TYPES OF LOADING SYSTEMS
24 H88
24 D66
24 D88
22 H88
22 D66
22 D88
19 H88
19 D66
19 D88
ATTENUATION - DB/MI
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0
FREQUENCY - KC/S

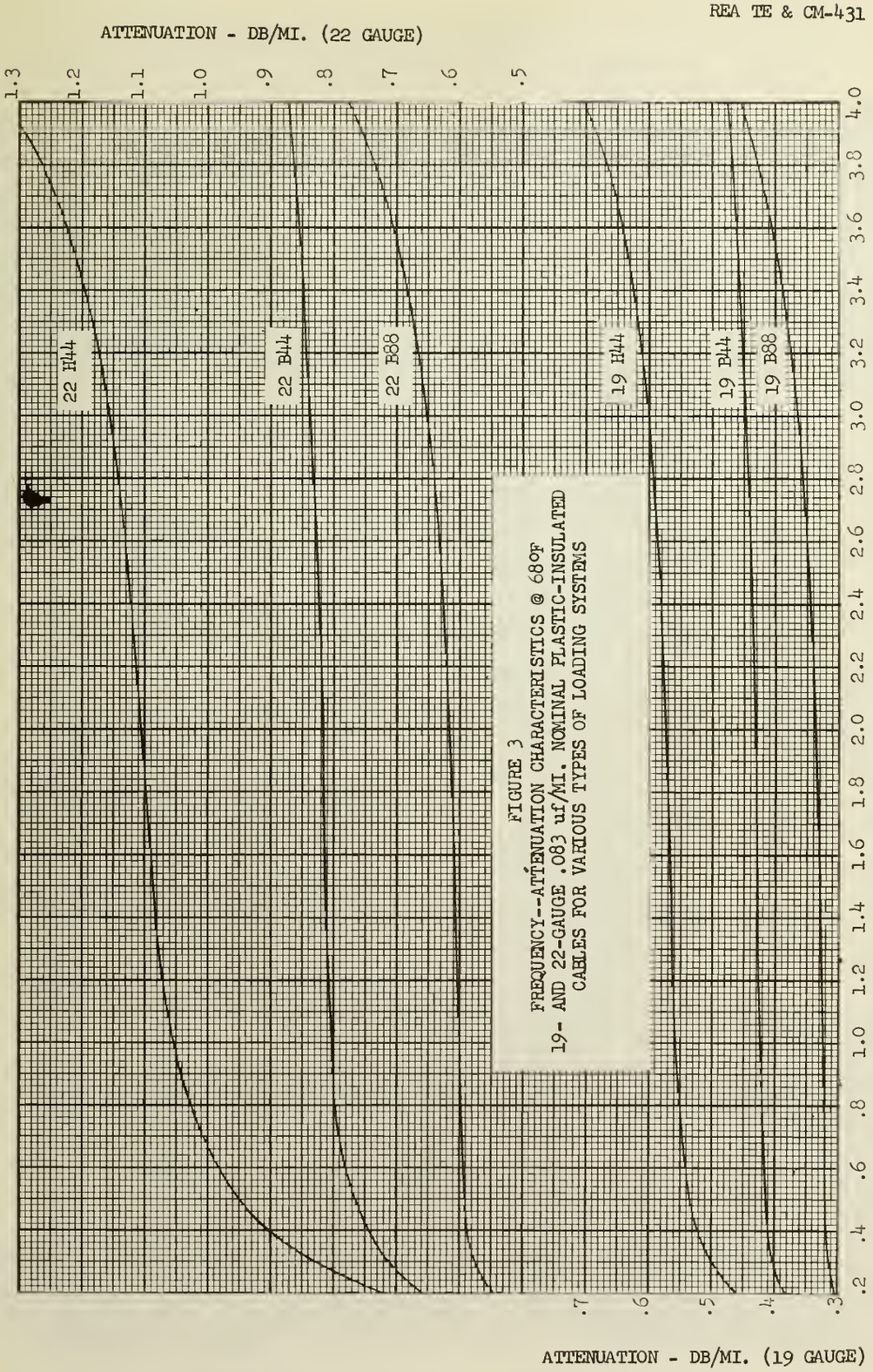
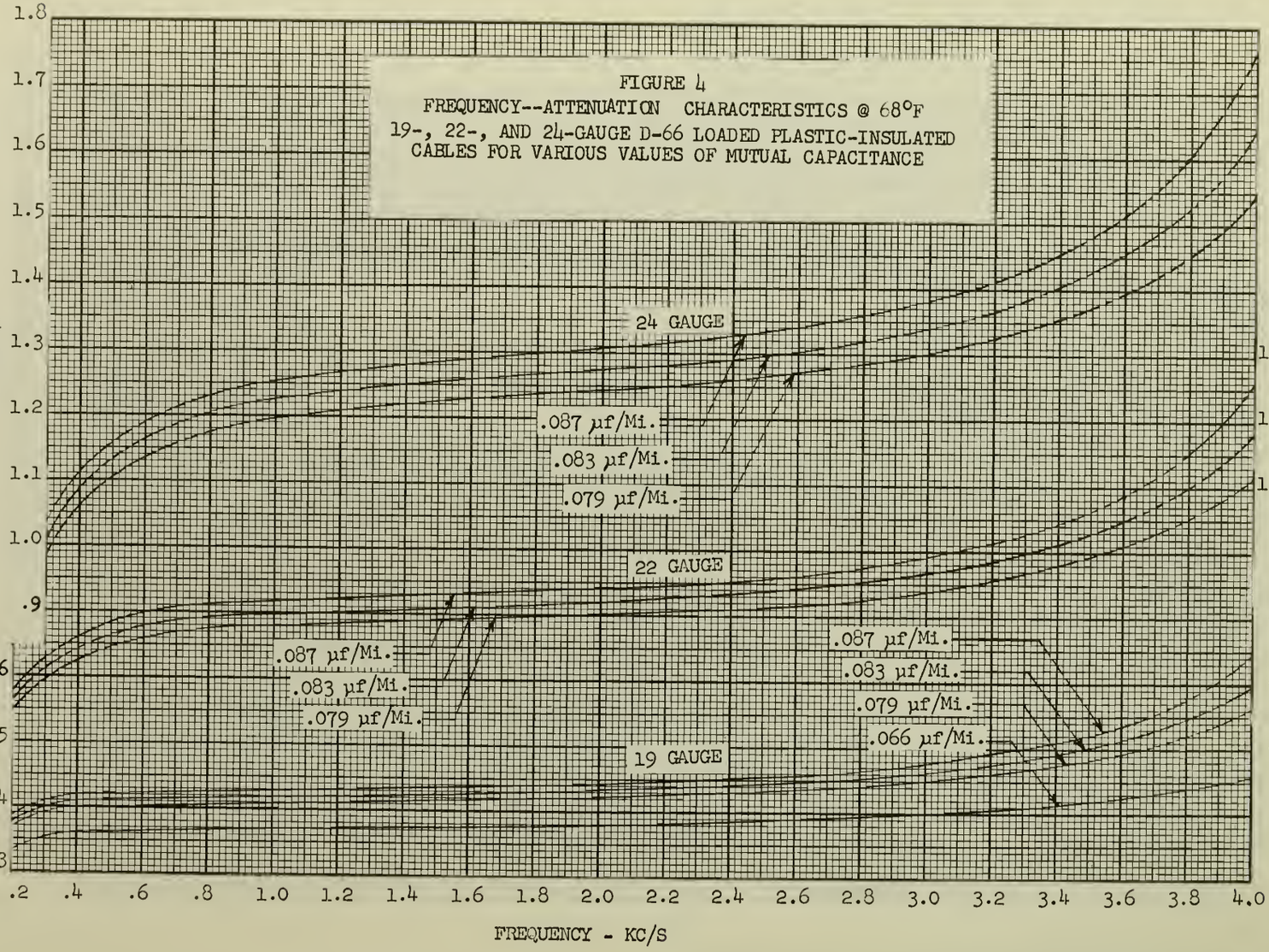


FIGURE 3
FREQUENCY--ATTENUATION CHARACTERISTICS @ 68°F
19- AND 22-GAUGE .083 uf/MI. NOMINAL PLASTIC-INSULATED
CABLES FOR VARIOUS TYPES OF LOADING SYSTEMS

FIGURE 4
FREQUENCY--ATTENUATION CHARACTERISTICS @ 68°F
19-, 22-, AND 24-GAUGE D-66 LOADED PLASTIC-INSULATED
CABLES FOR VARIOUS VALUES OF MUTUAL CAPACITANCE



24 GAUGE ATTENUATION - DB /MI.

19 GAUGE

FIGURE 5
FREQUENCY--ATTENUATION CHARACTERISTIC @ 68°F
19-, 22-, AND 24-GAUGE H-88 LOADED PLASTIC-INSULATED
CABLES FOR VARIOUS VALUES OF CAPACITANCE

FIGURE 6
FREQUENCY-MID-SECTION IMPEDANCE (MAGNITUDE) CHARACTERISTICS
19-, AND 22-GAUGE .083 uf/MI. NOMINAL CAPACITANCE
PLASTIC-INSULATED CABLES D-66 AND H-88 LOADED

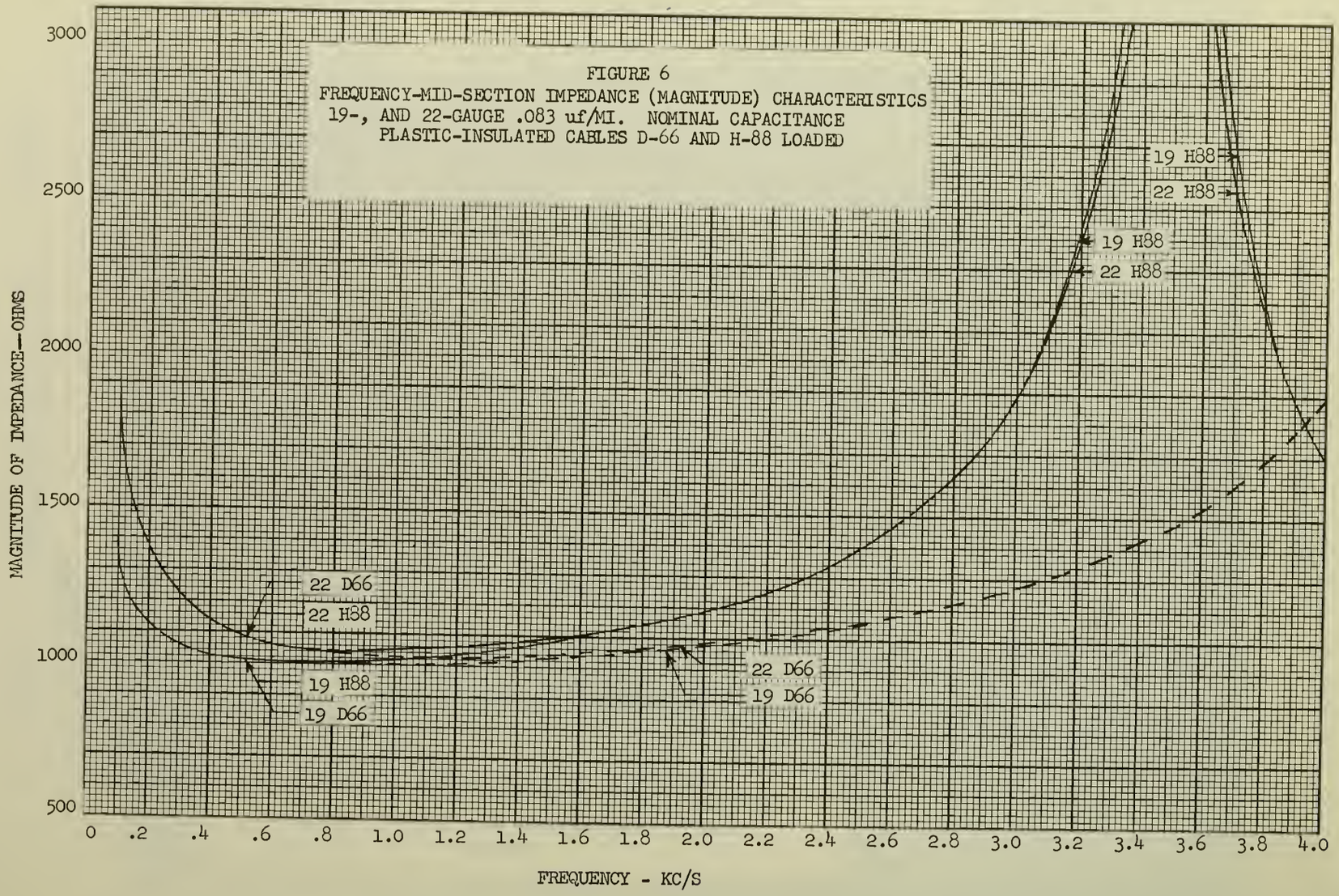


TABLE I

ATTENUATION AT 1000 CPS AND 68°F[1]
LOADED, POLYETHYLENE AND PAPER[2] INSULATED TRUNK CABLES
PAIRED OR QUADDED

1. PAIRED, MULTIPAIR SHIELDED CABLES

Type of Facility	Attenuation DB/Mi.	Attenuation DB/KF
24-D-66 HC	1.21	0.23
22-D-66 HC	0.792	0.15
19-D-66 HC	0.428	0.081
26-H-88 HC	1.79	0.34
24-H-88 HC	1.21	0.23
22-H-88 HC	0.798	0.15
19-H-88 HC	0.428	0.081
24-B-88	0.921	0.174
22-B-88	0.601	0.114
19-B-88	0.320	0.606
19-D-88 HC	0.375	0.071
19-H-88 LC (Paired or Quadded)	0.375	0.071

2. PAIRED, MULTIPAIR NON-SHIELDED CABLES (RDW TYPE)

19-D-66 (Figure 8)	0.49	0.093
19-H-88 "	0.49	0.093
22-D-66 (Former Type)	1.0	0.181
22-H-88 "	1.0	0.181
19-D-66 "	0.6	0.114
19-H-66 "	0.6	0.114

3. TOLL QUADDED CABLE—19 GAUGE

	Side Circuit DB/Mi.	Side Circuit DB/KF	Phantom Circuit DB/Mi.	Phantom Circuit DB/KF
H-31-18	0.549	0.104	0.459	0.087
H-44-25	0.470	0.089	0.391	0.074
H-88-50	0.349	0.066	0.301	0.057
B-88-50	0.259	0.049	0.232	0.044

NOTES:

1. For temperatures other than those shown above, change attenuation shown by ± 1 percent for each change in temperature of ± 5°F.
2. Western Electric Company types DNB, BSA, and DSM for 19-, 22-, and 24-gauge, respectively.

TABLE II

REFLECTION LOSSES IN DB AT 1000 CPS FOR DISSIMILAR FACILITIES

FACILITY		CABLE AND FIGURE "8" RDW														OPEN WIRE					RDW (FORMER TYPE)				600 OHMS
		26 GAUGE			24 GAUGE				22 GAUGE				19 GAUGE			109 STEEL		COPPER-STEEL			104 COPPER	22 GAUGE			19 GAUGE			
		D66 H88	B88	H44	D66 N.L.	H88	B88	H44	D66 N.L.	H88	B88	H44	D66 N.L.	H88	B88	H44	85-135	190	30% 104	40% 104	30% 080	40% 080		D66 N.L.	H88	H44	D66 N.L.	H88	H44	
CABLE AND FIGURE "8" RDW	26 N.L.	-0.2	-0.1	-0.1	0.1	-0.3	-0.2	-0.1	0.3	-0.4	-0.4	-0.2	0.9	-0.5	-0.5	-0.3	0	0.1	-0.1	-0.1	0	-0.1	-0.2	0.4	-0.4	-0.1	1.0	-0.6	-0.3	-0.4
	26 D66 or H88	X	0	0	0.1	0	0	0.1	0.5	0	-0.1	0.2	1.2	0	-0.1	0.3	0	0	0.2	0.2	0	0.1	0.4	0.7	0.1	0.2	1.5	0	0.3	0.4
	26 B88		X	0	0.2	0.1	0	0.3	0.8	0.2	0	0.5	1.8	0.2	0	0.6	0	-0.1	0.3	0.5	0	0.2	0.7	1.0	0.3	0.6	2.0	0.2	0.7	0.9
	26 H44			X	0	-0.1	0	0	0.4	-0.2	-0.2	0.1	1.0	0.2	-0.2	0	0.1	0.1		0	0.1	0	0	0.1	0.5	0.1	0.1	1.2	-0.2	0.1	0.1
	24 N.L.				X	-0.1	0.1	-0.1	0.1	-0.3	-0.1	-0.2	0.5	-0.5	-0.2	-0.4	0.2	0.4	-0.2	-0.2	0.2	-0.1	-0.3	0.2	-0.3	-0.2	0.6	-0.5	-0.4	-0.6
	24 D66 or H88					X	0.1	0	0.2	0	0	0.2	1.0	0	0	0.2	0	0	0.1	0.1	0	0	0.3	0.6	0.1	0.3	1.2	0	0.3	0.4
	24 B88						X	0.2	0.6	0.2	0	0.4	0.6	0.2	0	0.6	-0.1	-0.1	0.2	0.4	0	0.1	0.6	1.1	0.3	0.7	1.8	0.2	0.7	0.9
	24 H44							X	0.1	-0.1	0.1	0	0.6	-0.1	0	0	0.2	0.3	0	0	0	0	0	0.3	-0.1	0.1	0.8	-0.1	0	0
	22 N.L.								X	0	0.4	-0.1	0.1	-0.2	0.4	-0.3	0.8	0.9	0	0	0.5	0.2	-0.3	0	-0.2	-0.2	0.3	-0.2	-0.4	-0.6
	22 D66 or H88									X	0.1	0.1	0.7	0	0.1	0.2	0	0	0	0	-0.2	-0.1	0.2	0.3	0.1	0.2	0.9	0	0.2	0.3
	22 B88										X	0.3	1.3	0.1	0	0.5	-0.2	-0.2	0.1	0.3	-0.2	0	0.5	0.8	0.2	0.5	1.6	0.2	0.6	0.7
	22 H44											X	0.3	0	0.3	0	0.3	0.4	0	0	0.1	0	0	0	0	0	0.4	0	0	0
	19 N.L.												X	0.5	1.2	0	1.5	1.8	0.5	0.4	1.1	0.7	0	0	0.3	0.1	0	0.4	-0.1	-0.4
	19 D66 or H88													X	0.1	0.1	0	0	-0.1	0	-0.3	-0.1	0.1	0.2	0	0.1	0.8	0	0.2	0.3
	19 B88														X	0.4	-0.2	-0.2	0.1	0.2	-0.3	0	0.5	0.7	0.2	0.5	1.5	0.2	0.5	0.7
	19 H44															X	0.4	0.5	0	-0.1	0	0	0	-0.1	0	0	0.2	0.1	0.1	0
OPEN WIRE	109 Steel (85 or 135)																X	0	0.2	0.3	0.1	0.2	0.4	1.1	0.1	0.6	1.8	0	0.5	0.6
	109 Steel (190)																	X	0.3	0.4	0.1	0.2	0.6	1.3	0.2	0.7	2.0	0	0.6	0.7
	104 C.S. 30%																		X	0	0.2	0	0	0.3	-0.1	0.1	0.7	-0.2	0	0
	104 C.S. 40%																			X	0.2	0.1	0	0.1	0	0.1	0.6	-0.1	0	-0.1
	080 C.S. 30%																				X	0	0.2	0.7	-0.1	0.2	1.3	-0.2	0.1	0.1
	080 C.S. 40%																					X	0.1	0.4	-0.1	0.1	1.0	-0.2	0	0
	104 CU																						X	-0.2	0.1	0	0.2	0.2	0	0
RDW (FORMER TYPE)	22 N.L.																							X	0	-0.1	0.1	0	-0.3	-0.6
	22 D66 or H88																								X	0.1	0.6	0	0.1	0.2
	22 H44																									X	0.2	0.1	0	-0.1
	19 N.L.																										X	0.6	0	-0.3
	19 D66 or H88																											X	0.1	0.2
	19 H44																												X	0

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Rural Electrification Administration
Telephone Engineering and Construction Manual

BOOKSTACKS-
DOCUMENTS

Section 445
Issue No. 2
January 1965

HOW TO MAKE STRUCTURAL RETURN LOSS MEASUREMENTS

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4. WHAT IS STRUCTURAL RETURN LOSS
5. THE HYBRID AND THEORY OF OPERATION
6. PRINCIPLE UNDERLYING THE MEASUREMENT OF STRUCTURAL RETURN LOSS
7. REQUIRED TEST EQUIPMENT
8. STEP-BY-STEP MEASUREMENT PROCEDURE
9. EXPECTED MEASURED PERFORMANCE
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Figure 36 ESRL Measurements

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Data Sheet for Recording SFSRL Measurements
Data Sheet for Recording ESRL Measurements

1. GENERAL

1.1 This section is intended to provide REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers' telephone systems. It provides in particular, technical information for use when making Single Frequency Structural Return Loss measurements (SFSRL) and Echo Structural Return Loss Measurements (ESRL) on D-66, H-88 and D-66/H-88 loaded cable plant intended for trunk or subscriber loop applications. This section describes how to make the structural return loss measurements.

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1.11 This section provides specific information on the following:

1.111 The return loss theory underlying the measurements.

1.112 How to measure the structural return loss (SFSRL and ESRL) of uniform D-66 or H-88 loaded single gauge cables.

1.113 How to measure the structural return loss (SFSRL and ESRL) of D-66 or H-88 mixed gauge cables.

1.114 How to measure the structural return loss of D-66/H-88 loaded cables using the D-66/H-88 junction impedance compensator.

1.115 Required test equipment for conducting the measurements.

1.116 Component and wiring information for constructing test hybrids and D-66 and H-88 precision networks when the need arises.

1.117 Illustrative results of cables measured in REA borrowers' systems.

1.118 Data sheets for recording measurement data.

1.2 The measurements described herein are not applicable to loaded trunk cables which contain lengths of rural distribution wire, non-loaded cable, open wire conductors or trunk plant which consists entirely or predominantly of rural distribution wires. Issue No. 2 of this section replaces Section 445, Issue No. 1, in its entirety.

1.3 The actual step-by-step measurement procedures for SFSRL and ESRL are discussed in paragraph 8.

2. THE MID-SECTION IMPEDANCE OF A LOADED CABLE

2.1 For every telephone line with uniformly distributed constants, there is a value of impedance such that if the line is terminated in this impedance no reflections exist at that end. This impedance is known as the characteristic impedance of the line. The characteristic impedance can also be defined as the input impedance of an infinitely long line without regard to the value of the terminating impedance at the receiving end.

2.11 Regardless, however, of the definition used the important consideration is that <u>if a line is terminated in its characteristic impedance the reflected energy is zero at every point in the line.</u>

2.2 In a loaded cable the amount of inductance added by the loading coil is large as compared to the inductance of the cable pair (about 80 times to one for D-66 and H-88 loading). Since the impedance of any line increases as the inductance of such a line increases, this tends to raise the characteristic impedance of the line. Therefore, the value of the characteristic impedance of a loaded cable pair is generally higher than that of a non-loaded cable pair of the same gauge at the same frequency, except at very low frequencies where the loading is not effective and the two impedances are nearly equal.

2.3 A loaded cable differs significantly from a non-loaded cable in this respect. The inductance of the non-loaded cable pair is uniformly distributed (the same value of inductance for each small increment in cable length) whereas the loaded cable has its inductance lumped at discrete intervals (at intervals of 4500 feet, for example, for D-loading). Loading a cable produces two important characteristics:

2.31 The loaded cable now acts as a low pass filter with a cutoff frequency determined by:

$$f_c = \frac{1}{\pi \sqrt{LC}}$$

where L is the sum of the loading coil and cable pair inductance per full loading section length in henries, C is the cable pair mutual capacitance per full loading section length in farads and f_c the cutoff frequency in cps.

2.32 The value of the characteristic impedance of the loaded cable depends upon <u>the point in the end-section at which it is measured. That is, the value of this impedance is different at different points along the end-section</u>. The length of the end-section at the point of measurement is usually expressed as a percentage of the full load spacing for the particular loading system in question. For

example, if impedance measurements are made between the 2250 foot ends of a D-66 loaded system, these measurements would represent the impedance of the cable between 0.5 end-sections (ES) or better known as Mid-Section Impedance. For an H-88 loading system, the mid-section impedance would require only 3000 feet of end-section length.

2.321 Fig. 1 shows the variation in the magnitude of the mid-section impedance of a 22-gauge exchange type cable D-66 and H-88 loaded in the frequency range of 200 to 4700 cps, including the region of the cutoff frequency. From inspection of the H-88 curve, it will be seen that the characteristic impedance remains relatively flat at approximately 1000 ohms in a very narrow frequency range of 700 to 1300 cps. At other frequencies large impedance changes occur with changes in frequency. The D-66 impedance curve displays less variation in the same frequency range. At 3000 cps, for example, its mid-section impedance rises only to 1270 ohms. To illustrate the effect which the length of the end-section has on loaded line impedance, Fig. 2 shows such a typical variation for a 24 and 22 gauge exchange type cable D-66 loaded as a function of both frequency and end-section length. At 3000 cps the characteristic impedance for the 22-D-66 is 1270-j80 ohms for the 0.5 end-section while at 0.3 it becomes 994-j563 ohms. Therefore when making structural return loss measurements, end-section lengths must be known accurately since they can affect the results of the measurements in a major way.

2.322 It should be borne in mind that REA TE & CM-431, "Voice Frequency Loading for Trunk Cables," and REA TE & CM-424, "Design of Subscriber Loop Plant", require that plant be designed and built on the basis of 0.5 end-sections or 2250 feet for D-66 loading. Other applicable REA Telephone Engineering and Construction Manual sections dealing with attenuation and reflection losses of loaded cables have been prepared on the basis of 0.5 end-sections or mid-section impedances.

2.4 Short Rules to Remember:

2.41 If a loaded cable is infinite in length (in practical terms, 15 db or longer one-way attenuation at 1000 cps) what happens to its far-end terminal has no effect on the impedance seen at the near-end terminal. This means that the termination at the far end can vary, for example, from 100 million ohms to one ohm (actually from an open to a short) and this does not change the value of the near-end impedance.

2.42 The mid-section impedance of a loaded cable which is infinite in length means the impedance of a loaded cable when looking into it from an end-section which is one-half the length of a full loading section and whose far-end section is also one-half the length of a full section.

3. THE PRECISION BALANCING NETWORK

3.1 The successful performance of negative resistance (E-6 type), negative impedance (E-23 type) and hybrid voice frequency repeaters depends not only on their design characteristics but also on the electrical characteristics of the plant facilities over which they are to operate. Fundamentally, good performance depends on the degree of match possible between the plant impedance and the repeater network impedance at all frequencies. Though in the case of hybrid-type repeaters operating on a two-wire basis transmission within the repeater amplifiers is unidirectional (two separate amplifiers required, one in each direction of transmission) while in the negative resistance and impedance type it is bidirectional, both modes of operation depend on proper impedance match between their respective impedance networks and the plant impedance. Essentially, the better the impedance match, the more repeater gain is possible. Devices which make this match possible are precision balancing networks more commonly known as balancing networks.

3.2 Two-terminal networks which very closely simulate the impedance of the type of plant over which voice frequency repeaters are intended to operate, over the entire frequency range of interest, are termed Precision Balancing Networks and abbreviated PBN. Precision balancing networks which simulate the impedance of two types of loading systems (D-66 and H-88) at all frequencies of interest are an integral part of the equipment required for making the structural return loss measurements described herein.

3.21 Fig. 3 shows the configuration of the REA design for a precision balancing network which matches the mid-section impedance of 19, 22 and 24 gauge exchange type cable D-66 loaded (its impedance is shown in Fig. 1). The design shown in Fig. 3 can be conveniently made up if the parts, to the values shown, are locally available. The C-115DL precision balancing network made by the Ceeco Company or the Communication Apparatus Corporation type 115DL or its equivalent may also be used.

3.22 The W. E. Co. 115H or the Ceeco C-115H PBN's are used for 19 and 22 gauge cables H-88 loaded. For 24-H-88 loaded cable the W. E. Co. type 115AL PBN must be used.

3.3 Short Rules to Remember:

3.31 A precision balancing network is a two-terminal device which simulates the impedance of an infinitely long loaded cable over the entire frequency range of the loading system.

3.32 A loaded cable which is finite in length (all applications encountered in common practice are included under this definition of finite) can be made to have its impedance look like the impedance of a loaded cable which is infinite in length. This can be done by connecting a precision network at the far-end terminals of the cable; the impedance seen at the near-end terminals is now the infinite line impedance. In addition, if the end-section at the near-end is 0.5, the resulting impedance is termed the mid-section characteristic impedance or the mid-section infinite line impedance.

4. WHAT IS STRUCTURAL RETURN LOSS (SRL)

4.1 Fig. 1, which displays the mid-section infinite line impedance characteristics of 22-D-66 cable shows a uniform curve at all frequencies with no evidence of even minor impedance irregularities. This is as it should be, since the assumptions on which the derivation of this curve have been based assume the loaded cable pair in question to have ideal characteristics, that is:

a. The cable mutual capacitance for each 4500 feet loading section (6000 feet for the H-88) is precisely the same.

b. The loading coil inductance at each load is precisely the same.

c. The physical distance between each two consecutive load coils is precisely 4500 feet (6000 feet for the H-88).

4.2 In an actual loaded cable the above factors cannot be made ideal due to practical considerations relating to manufacture and construction. Some of these are:

a. Variation of cable pair mutual capacitance mainly from pair to pair and from reel to reel.

b. Variation of coil inductance from loading coil to loading coil.

c. Practical staking, construction and maintenance problems do not permit placing loading coils at exact specified intervals.

4.3 To the extent that the cable pair mutual capacitance, the loading coil inductance and load coil spacing all may depart from their assigned value and that the variables in question may occur in any random manner and relative degree, the smooth impedance characteristic of Fig. 1 has now been somewhat altered. These small impedance variations compared to the ideal impedance result in small reflection currents which eventually reach the near-end or point of measurement. The overall value of these small reflected currents is known as structural return loss and is usually expressed in db. The greater the reflection current the lower will be the structural return loss in db and the poorer the circuit performance will be. An ideal cable which has not even small irregularities has zero reflected currents and therefore its structural return loss is infinite. Structural return loss therefore is a figure of merit of the completed cable plant with regard to impedance uniformity and it reflects the quality of uniformity (or lack of it) in the mutual capacitance of the cable product, the quality of uniformity (or lack of it) in the inductance of the loading coil product and the care with which the plant has been staked and loading coils accurately placed (or lack of accuracy). The greater the care and better the methods used to build plant the higher the figure of merit of the plant will be and the higher the structural return loss. High values of structural return loss mean plant with high performance capability.

4.31 Strictly speaking, the structural return loss of a loaded cable is an index of the departure of the impedance of the actual circuit under measurement from the ideal characteristic impedance. Since, however, the precision balancing networks discussed in this section precisely simulate the ideal characteristic impedance, the structural return loss is taken as the balance between the cable circuit under test and its corresponding precision balancing network used for the test.

4.4 Since the structural return loss is dependent on the random combination of a large number of small reflected currents due to the factors in paragraph 4.2 above and in addition the phase of the reflected currents vary with frequency, the resulting structural return loss displays peaks and valleys over the frequency range measured. Examples of actual loaded cable pairs shown in Figs. 20-30 show the peak-and-valley-frequency effect. Structural return loss values are extremely high. This is indicative of cable plant with good figure of merit and therefore containing very small random irregularities.

4.5 An examination of the SFSRL plots in Figs. 20-35 will indicate that there is some frequency where the value of the SRL is the lowest. This frequency together with this lowest (worst) SRL value within the 300 to 3000 cps range is known as the Critical Frequency Structural Return Loss (CFSRL). It is this value of CFSRL in REA TE & CM-444, "Calculation of Net Loss of Negative Impedance Repeatered, Loaded Trunks", and REA TE & CM-446, "Design of Two-Wire D-66 Loaded Negative Resistance Repeatered Trunk Plant", which is used to compute repeater gains. For example, reference to Fig. 20 shows the CFSRL value to be 35.2 db at the critical frequency of 2400 cps.

4.51 Important Note: In Figs. 20-30 the critical frequency structural return loss is also shown for a frequency range between 300 to 3400 cps, indicated as "3400 cycle band". With the D-66 loading system the cutoff frequency is well beyond 4500 cps and this means that a frequency band up to 3400 cps can be quite usable. The present voice frequency repeater equipment and 500 type telephone sets transmit well up to 3400 cps. Further, many new trunk carrier systems are now being engineered for a 300 to 3400 cps band while others are being modified for improving their bandwidth characteristics. Therefore, when making acceptance tests on D-66 loaded cable plant, not only the 3000 but the 3400 cycle band CFSRL should be recorded.

4.6 Single Frequency Structural Return Loss (SFSRL)

4.61 As discussed in paragraph 4.31 above the essential factor when making structural return loss measurements is that the cable pair at its far-end, and at the test hybrid on its network side must each be terminated in precision networks which match the impedance of the cable over the entire frequency range of interest to be measured. Therefore, measurement under precision network terminations constitutes a structural return loss measurement. In addition, if the measurements are made with conventional single frequency oscillator and AC-VTVM equipment, using point-by-point techniques measuring each frequency separately, the measurements are further termed single frequency or SF. Structural return loss measurements using point-by-point methods are termed Single Frequency Structural Return Loss or SFSRL. Paragraph 4.5 above refers to SFSRL type of measurements.

4.62 Devices of the single frequency oscillator and AC-VTVM type are available which measure the entire frequency range of interest in a loaded cable by sweeping through the entire range. Such equipment is known as Swept-band Oscilloscopes or Level Tracers and make possible substantial simplifications in testing. Their use is discussed in paragraph 7.2 below.

4.63 The step-by-step measurement procedures for making the SFSRL measurements are discussed in paragraph 8.

4.7 Echo Structural Return Loss (ESRL)

4.71 In addition to the point-by-point, single frequency procedures of paragraph 4.6 above other methods are available which measure the structural return loss by a single measurement only. This is accomplished by a source of random noise which replaces the single frequency oscillator and a noise measuring set, replacing the AC-VTVM. The energy from the noise generator is evenly distributed throughout the voice frequency range. That is, all frequencies are present at the same time and approximately in the same amount of power. Because the noise source generates a wide band of frequencies, a network is provided to shape its output to match the frequency characteristics to normal message telephone channels. The band of frequencies used for this purpose range from 500 to 2500 cps.

4.72 The "echo" band in a message telephone circuit is considered to occupy the frequency range between 500 to 2500 cps.[1] It is thought to be representative of the frequencies which are important during talking conditions. Structural return loss measurements made with random noise equipment in this frequency range are classed Echo Structural Return Loss Measurements and abbreviated ESRL. The generator used to supply the random noise is the W. E. Co. 201B Noise Generator using a 455B weighting network or the Northeast Electronics Company type TTS 56. The detector used to measure the returned noise power is the W. E. Co. 3A Noise Measuring Set using C-message weighting or the Northeast Electronics Company type TTS 37B or equivalent.

4.73 The step-by-step measurement procedures for making the ESRL measurements are discussed in paragraph 8.

5. THE HYBRID AND THEORY OF OPERATION

5.1 Throughout the above mentioned discussion of structural return loss the existence of a device capable of measuring this quantity has been tacitly assumed. This device is the hybrid coil or more generally known as the hybrid. While the hybrid may be described in various ways, it accomplishes the basic function of separating the two directions of transmission in an otherwise bidirectional transmission medium. That is, it provides with other associated equipment, a means for the transmit and receive branches of a circuit which are fundamentally derived on a four-wire basis to be routed over the same two-wire bidirectional line with emphasis on keeping the interaction to a minimum. It should be noted that resistors may also be used as elements for performing a hybrid-type function.

5.2 The hybrid is an indispensable component of the telephone plant. Due to its inherent capability of providing direction-of-transmission separation it did in fact make the introduction of electronic amplification in telephone plant possible and in this respect made long distance communication possible. The uses of the hybrid are many and varied. Some of the more prominent hybrid applications are listed below.

[1] AT&T Company's "Notes on Distance Dialing", 1961, Section 6.

5.21 In the Telephone Set. To separate the "transmitter" from the "receiver" branch.

5.22 On Two-Wire Operation of "V" Type Repeaters. To separate the four-wire transmission within the repeater from the two-wire line, where two-wire-line transmission is involved.

5.23 On Four-Wire Operation of "V" Type Repeaters. To combine the four-wire-line transmission to the user's two-wire telephone line. A hybrid operating in this manner is often known as a Four-Wire Terminating Set.

5.24 In Carrier or Multiplex Radio Circuits. All carrier derived circuits whether transistorized or vacuum tube, trunk or subscriber, open wire or cable, operate essentially on a four-wire basis. That is, each direction of transmission is electrically separated from the other direction. Hybrids are used for routing both directions of voice frequency over the same two-wire line. In this respect, it is similar to the "V" type repeater described in paragraph 5.23 above.

5.25 Terminal Balance for VNL Circuits. Intertoll trunks, designed according to present transmission practices operate at very low net losses. To make this possible without objectionable echo or singing an extensive degree of balancing must be applied. Of the devices used for making this possible, the hybrid is an integral part.

5.26 Measurement of Return Loss. This may include the return loss of two dissimilar impedances, the degree of terminal balance of a toll center, the return loss characteristics of a subscriber loop or generally any measurement which seeks to establish the degree of balance or match between the quantities under consideration.

5.3 Figure 5 shows several examples where hybrids are required for the application intended, while Figure 6 shows some of the different types of hybrids in use.

5.31 In examining the manner in which the hybrid accomplishes its intended function, the Wheatstone Bridge analogy offers a convenient means of explanation. For example, the four arms of the bridge can be thought of as the four essential elements normally associated with the hybrid. These are:

A. The "transmit" branch.

B. The "receive" branch.

C. The two-wire line branch.

D. The network branch.

Fig. 7 shows the Wheatstone Bridge equivalent of the hybrid circuit and all of its associated components.

5.32 In Fig. 7, when the arm R_1 equals arm R_2 and arm R_N equals R_W, there is no difference of potential across the galvanometer terminals (G) and therefore no current flows through it. The galvanometer therefore is at a null or the bridge is balanced. If arm R_1 still remains equal to arm R_2 but now arm R_N is not equal to arm R_W then there is a difference of potential across the galvanometer terminals and a current flows through it. This is a current caused by the unbalance and its magnitude is determined simply by the degree of mismatch between R_N and R_W.

5.33 In Figs. 7B and C the basic Wheatstone Bridge circuit is applied to the operation of the hybrid coil. For this reason the battery has been replaced by an oscillator, the galvanometer by a detector or transmission measuring set and the resistors with impedances. When Z_1 equals Z_2 and Z_{net} equals 2-wire line there is no difference of potential across the detector terminals and therefore no current flows through it. The detector is therefore at a null or the bridge is balanced. When Z_1 still equals Z_2 but Z_{net} is no longer equal to Z_2-wire line there is a difference of potential across the detector terminals and a current flows through it. This is a current caused by the unbalance and its magnitude depends on the degree of mismatch between Z_{net} and Z_2-wire line. If the degree of the impedance match, measured as mentioned above, is that of a loaded line and its respective precision balancing network, the measurement is basically structural return loss which this section shows how to make.

5.4 The above discussion has served to provide a general understanding of the hybrid operation. In the paragraphs below, a more thorough explanation is now given by reference to Fig. 8 which shows a coil type hybrid having connected to its appropriate terminals an oscillator, a detector, a network and the two-wire line which match the impedances for which the hybrid has been designed. The resulting hybrid action when changes take place in certain of the hybrid terminals is as follows:

5.41 If the line contains no irregularities, the signal from the oscillator terminals causes equal current to flow in the Two-Wire Line and Network and no current enters the Detector. That is, one-half the power delivered by the Oscillator to the hybrid coil goes to the Two-Wire Line and the other half to the Network. Therefore there is a 3 db (3.01 db to be more exact) loss between the Oscillator and the Two-Wire Line.

5.42 If however, the line contains irregularities, part of the energy on the Two-Wire Line (which is already 3 db down) re-enters the hybrid. Again, one-half of this returned energy goes to the Detector and the other half to the oscillator. Therefore there is a 3 db loss between the Two-Wire Line and the Detector. Thus the total hybrid transmission loss between the Oscillator and Detector is 3+3 db or 6 db.

5.421 The 6 db transmission loss between the Oscillator and Detector above assumes an "ideal" coil hybrid; that is one which does not have iron or copper losses. With practical hybrids (that is, made out of physical components) these copper losses usually amounting to 0.25 to 0.5 db must be added twice to the above 6 db thereby making the actual loss about 6.5 to 7.0 db (say 7.0 db).

5.422 The transmission loss of 7.0 db through the hybrid, in the presence of line irregularities, must not be confused with the structural return loss, though inherently the measurement of the structural return loss includes this 7.0 db automatically. Stated in another way, when making the structural return loss measurements, this 7.0 db loss characteristic of the hybrid coil must be accounted for (subtracted).

5.43 In Fig. 8, if the hybrid terminals where the Two-Wire Line is connected are open-circuited or short-circuited the resulting transmission loss through the hybrid will be 6.5 to 7.0 db as above. This is because the power division within the hybrid coil as described in paragraph 5.41 still takes place but in addition there is now a return loss between the impedance of the Network and the open or shorted terminals of the Two-Wire Line side of the hybrid which must be added. This return loss however is 0 db so that the total loss again is 6.5 to 7.0 db. Note: When making the actual measurements, described in paragraphs 7 and 8 the trans-hybrid loss is automatically accounted for at all frequencies of measurement during the calibration procedure.

5.44 Another significant property of the coil hybrid indispensable in singing point work (for determining available gain of "H" type repeaters) but mentioned here only for completeness is that if the Network terminals of the coil hybrid are alternately opened or shorted while the Two-Wire Line hybrid terminals are being shorted or opened, the coil hybrid acts as though it were essentially a repeating coil. The only transmission loss incurred is the normal insertion loss of the coils.

6. PRINCIPLE UNDERLYING THE MEASUREMENT OF STRUCTURAL RETURN LOSS

6.1 Fig. 8 shows the connections of the test equipment and cable pair under test for the measurement of the cable structural return loss. By reference to this figure the principle underlying the structural return loss measurements can now be summarized as follows:

The coil hybrid acts as an a.c. bridge. In this bridge:

A 600 ohm oscillator and a 600 ohm detector make up two of the arms of this bridge. Since their impedances are equal and at 600 ohms, they do not directly enter into the measurement of the structural return loss.

The precision balancing network on one side of the hybrid and the cable pair under test terminated in a similar precision balancing network on the other side make up the remaining other two sides of the bridge. It is the variations in these two sides of the bridge which give rise to the structural return loss.

Now, precision balancing network (A) precisely matches precision balancing network (B). If in addition, the cable under test precisely matches precision balancing network (B), these two arms of the bridge are perfectly balanced, there is no reflected energy, no current flows through the detector, the detector reads zero and therefore the structural return loss is infinite.

If the cable under test contains irregularities its impedance does not match network (B) and the two arms of the bridge are unbalanced, energy is returned to the hybrid, current flows through the detector and a finite reading is obtained. This reading corresponds to the value of the structural return loss at the frequency of measurement.

7. REQUIRED TEST EQUIPMENT

7.1 The following type and number of measuring equipment is required for making the SFSRL measurements in D-66, H-88 and D-66/H-88 loaded cables:

7.11 Two W.E. Co. 120P or Altec Lansing Co. 15189 repeating coils wired as per Figure 9 for making up coil test hybrid or Ceeco Co. type C-101A Test Hybrid or other equivalents.

7.12 One, Hewlett Packard Co. type 204B, 200CD, 200J oscillator or equivalent.

7.13 One, Hewlett Packard Co. 403B, A, 400D, H, L AC-VTVM or equivalent.

7.14 One, 600 ohm, ± 1%, 1 watt carbon resistor on double banana plug.

7.15 Two precision networks for 19, 22 or 24 gauge D-66 loaded cables. REA design of Figure 3 or Ceeco Co. type C-115DL, or CAC Co. type 115DL.

7.16 Two precision networks for 19 or 22 gauge H-88 cables, W. E. Co. type 115H, or Ceeco Co. type C-115H or C-100 Test Set or equivalent. Two precision networks for 24 gauge H-88 loaded cables, W. E. Co. type 115AL.

7.17 Two decade capacitor boxes, Ceeco Co. type C-100 Test Set or Heath Co. type DC-1 or Precise Co. Type 478.

7.2 Oscilloscopic equipment of the swept frequency type, also known as Level Tracers, can be used for making the SFSRL measurements which very substantially reduces the measurement time and effort. The Siemens-Halske Co. type Rel 3K 211b Level Tracer and the Hallamore Co. type TMS-0100 of Swept Band Set can be used. The Siemens-Halske type Rel 3K 211b Level Tracer can be used for both the H-88 and D-66 loaded cables since its upper frequency limit is 6000 cps. The Siemens Level Tracer also contains a built-in hybrid, thereby eliminating the need for the external hybrid discussed in paragraph 7.11.

7.3 The following type and number of measuring equipment is required for making the ESRL measurements in D-66, H-88 and D-66/H-88 loaded cables:

7.31 Hybrid, precision network and capacitor building-out equipment as per paragraphs 7.11, 7.15 (and 7.16) and 7.17, respectively.

7.32 One W. E. Co. 201B Noise Generator with 455B Network, or N. E. Electronics Co. TTS-56 or equivalent.

7.33 One W. E. Co. 3A Noise Measuring Set or N. E. Electronics Co. TTS-37B or equivalent.

8. STEP-BY-STEP MEASUREMENT PROCEDURE

8.01 The type of test equipment, equipment connections, calibration and measurement procedure for D-66, H-88 and D-66/H-88 loaded cables are shown in Figs. 10-14 for the SFSRL measurements and Figs. 15-19 for the ESRL measurements. The discussion in paragraphs 8.1 and 8.2 below apply directly to the SFSRL measurements. Paragraph 8.5 discusses ESRL considerations.

8.1 Frequency Range Which Must Be Measured

8.11 The band of frequencies which must be measured is from 200 cps to 4500 cps for D-66 and up to 3500 cps for H-88 and D-66/H-88 compensated cables. The critical frequency structural return loss, abbreviated CFSRL, is the lowest value of structural return loss between 300 and 3000 cps. It is this value which is used in carrying out the repeater circuit design when computing available repeater gain and the resulting net loss.

8.2 Sending Level and Calibration for SF Measurements

8.21 Because the test equipment setup is calibrated to produce 0 dbm (zero dbm) on the detector when the hybrid "Line" terminals are short-circuited, the direct reading of the AC-VTVM in minus dbm is the actual value of structural return loss in db when making the measurement and no other correction to the meter reading is needed. This is illustrated in Figs. 10-14.

8.22 The above calibration procedure for setting the oscillator output level to produce 0 dbm on the AC-VTVM when the hybrid "Line" terminals are shorted is but one method for calibrating out the transhybrid loss. That is, the power division loss which is inherent in every coil type hybrid and is 3 db in each direction plus core losses of 0.3 to 0.5 db or approximately 7.0 db total. This transhybrid loss must not be charged to the measurement and for this reason it is calibrated out.

8.23 The same result can be obtained by calibrating out from the measurement the 7 db transhybrid loss by using an alternate method. This is to connect the 600 ohm oscillator directly into an external 600 ohm resistor and set the oscillator output level to read +7 dbm on the AC-VTVM across the external 600 ohm resistor. Either calibration method will give the same results. When using this method the SRL in db is again the direct reading of the AC-VTVM in minus dbm. For example, with the cable connected if the reading of the AC-VTVM is -29 dbm, at a given frequency, the SRL value is 29 db at the same frequency.

8.24 There can be many calibration levels which can be used which will give the same overall results. The reason that the method of paragraph 8.22 or 8.23 is used is because they are simple and allow the readings to be direct. No corrections are necessary and this saves time. Sometimes it also eliminates simple mistakes such as adding or subtracting. But if for some reason other calibration levels are necessary, good results can still be obtained. For example, if the calibration is performed as follows: Connect the 600 ohm oscillator directly into the external 600 ohm load and set the oscillator output level for the AC-VTVM which is connected across the 600 ohm resistor to read 0 dbm (zero dbm). Now when the oscillator (with its output level control unchanged) is connected into the hybrid and the SRL measurement is made, the readings in the AC-VTVM will no longer be direct. Because the 7 db (approximately) transhybrid loss has not been accounted

for in the calibration the readings on the AC-VTVM will be lower (SRL will look better by 7 db) so that 7 db must be subtracted from the SRL reading. Assume, for example, when using this calibration method the AC-VTVM reads -32dbm when the measurement is made. This means that the SRL reading is 32 db but the correct value of SRL is 32 -7dbm or 25 db. Assume that the calibration level for the same example has been -10 dbm for a valid reason. When the SRL measurement is made this means that 10 + 7 or 17 db must be subtracted from the meter reading to obtain the correct SRL value!

8.25 Some of the more important reasons for calibrating at levels lower than that of paragraph 8.11 may be to avoid possibility of inducing interference into other working pairs or the test equipment may not be capable of delivering the +7 dbm required for the direct (no correction) measurement. The type of equipment shown herein is capable of an output level of +7 dbm into an external 600 ohm resistor so that this will not be a problem.

In summary, any calibration method can be used and will give good results if one is careful to make the appropriate corrections in the meter readings. The methods of paragraphs 8.22 and 8.23 are direct and do not require corrections; whatever the meter reads, that is the answer also. The calibration methods of paragraphs 8.21 and 8.23 are used in Figs. 10-14 and all SFSRL examples herein.

8.3 Sending Level and Calibration for Echo Measurements

8.31 The discussion in the above paragraphs for SFSRL measurements apply equally well to the ESRL measurements with regard to the 7 db transhybrid loss and calibrating levels. The detector equipment, however, used in the ESRL measurements is calibrated in different units; namely dbrn-C. For this reason some modification of the terminology is necessary and a brief explanation of this is given below:

8.32 The 3A NMS will read 0 dbrn-C in "N_M-600 ohm", "Flat" or "C-Message Wt." position when a test tone of -90 dbm at 1000 cps is applied to its input terminals and 90 dbrn-C with a 0 dbm, 1000 cps test tone. Single frequency test power inputs at frequencies other than 1000 cps are properly weighted by the 3A NMS when in the "C-Message Wt." position, according to frequency. When the 201B Noise Generator is set for an output of 0 dbm power the corresponding reading on the 3A NMS C-Message Wt., is approximately 90 dbrn-C when the two are directly connected. If the noise generator, set for the same output power, is now connected through the hybrid for the ESRL measurement (PBN connected on one 2-wire side of the hybrid with the other side open or shorted) the new reading on the 3A will be approximately 83 dbrn-c. The 7 db reduction in power is the transhybrid loss due to the coil hybrid. To account for the 7 db transhybrid loss the Noise Generator output is set for +7 dbm (97 dbrn-C directly into the noise generator) which is approximately 90 dbrn-C when connected with the test hybrid in the calibrate position. In the measuring position, when the cable pair under test is connected to the hybrid terminals the reading on the 3A NMS becomes lower. The difference between the 90 dbrn-C in the "calibrate" position and the new dbrn-C reading in the "measure" position is the ESRL value in db.

8.4 Correct Settings for Precision Balancing Networks

8.41 A discussion is given of the components in a precision balancing network (abbreviated PBN) used in the measurement because if improperly connected or used it can lead to SRL measurements which are not correct. The PBN used in the measurement consists of three parts:

a. The basic network

b. Components for making the end-section variable for H-88 loading only.

c. Components for changing the gauge from 19 to 22 or 24.

8.42 The basic network in (a) consists of capacitors, inductors and resistors to simulate D-66 loading with 2250 feet end section (0.5 or mid-section impedance) but only 900 feet end section for H-88 loading. These components are permanently connected and not externally accessible for changing.

IMPORTANT NOTE: THE REASON THAT THE D-66 BASIC NETWORK IS A FIXED 2250 FEET IS BECAUSE D-66 LOADED TRUNK CABLES ARE ENGINEERED TO HAVE 2250 FOOT END SECTIONS (0.5 END SECTIONS). EXISTING H-88 CABLES ON THE OTHER HAND, ARE FOUND WITH MANY END SECTION LENGTHS AND THE BASIC NETWORK IS THEREFORE MADE VARIABLE TO ACCOMMODATE THIS.

8.43 As pointed out in paragraph 8.42 above, for D-66 loaded cables the basic end section of the precision network is 2250 feet without any additional building-out capacitor. For H-88 loading, a variable capacitor (CBO) is provided with the basic network for building-out to the particular length of the end section of the cable. The capacitance of both this CBO in the PBN in microfarads (or feet) plus the basic network equivalent capacitance determines the total end-section value of the PBN. For example, to set a D-66 PBN to have a total end section of 0.5 (2250 feet) the amount of CBO required is:

2250' -2250' = 0 feet, additional

To set an H-88 PBN to have a total end section of 0.5 (3000 feet) the amount of CBO required is:

3000' -900' = 2100 feet, additional

This 2100 feet is strapped in building-out capacitor CB01 shown in Figs. 13-14 and 18-19 for H-88 loading.

8.44 Resistors and capacitors are also included in the PBN for the correct cable gauge. In D-66 loaded cables the same PBN is used for 19, 22 and 24 gauge exchange type cables. For H-88 loading the same PBN can only be used with 19 and 22 gauge exchange type cables. For 24 gauge, H-88 loaded, a separate network must be used (W. E. Co. 115AL). For D-66 PBN's the gauge is readily set by a simple strap or by a switch which selects the desired gauge. For H-88 PBN's this is not possible. The gauge terminals are numbered and the numbers are different for the various manufacturers. For this reason, for H-88 loading, consult the instructions of the manufacturer for the particular PBN used in the measurement.

8.45 The terminals of the PBN which connect to the "NET" side of the hybrid are normally numbered 1 and 2 for the particular type of units shown herein. The CBO where used is also strapped across the same terminals 1 and 2. (Consult the instructions of the manufacturer if other type of PBN is used for the actual terminal numbering - they can be different.)

8.46 As discussed in paragraph 8.4 above, because D-66 loaded trunk plant is engineered and built for 2250 feet end sections the structural return loss measurement is made with D-66 PBN's having 2250 feet end sections. The Ceeco (Communication Equipment and Engineering Company) type C-115DL PBN and the CAC (Communications Apparatus Corporation) type 115DL PBN are networks with such built-in 2250 foot end sections. For this reason the additional building-out capacitor shown as CB01 in Figs. 13-14 and 18-19 for H-88 loading is not required with D-66 loading. In Figs. 10-12 and 15-17 for D-66 loading no CB01 capacitor is shown in the PBN.

8.47 For H-88 loading or for measuring at the H-88 end of a D-66/H-88 loaded cable the basic PBN end section is 900 feet. This was discussed in paragraph 8.42 and in the example given in paragraph 8.43. For making measurements therefore on H-88 cables having 0.5 end sections (3000 feet) additional capacitance is required in the basic H-88 PBN. This is the function of capacitor CB01 shown in Figs. 13-14 and 18-19. The value of this capacitor is set as follows:

Basic PBN Capacitance	= 900 feet
Total Required Capacitance	= 3000 feet
Difference	= 2100 feet

Therefore, before proceeding with the measurement, capacitor CB01 is set for 2100 feet because this represents a capacitance value of 0.033 microfarads based on 0.083 microfarad per mile cable.

8.48 Having connected the PBN's 1 and 2 for 0.5 end sections, as discussed above, the SRL measurement is made and the results entered in the "Data Sheets".

8.5 Maximizing the Structural Return Loss

8.51 The structural return loss measurement made with the PBNS' set for 0.5 end sections as described above does not normally yield the best structural return loss which the loaded cable is capable of. Though the measured value may be sufficiently high the actual value itself may be even better than this. In other cases the results of the measurement may be indicative of an apparent poor return loss in the outside plant. The reasons for this are as follows:

a. The cable may not be exactly 0.5 end section in physical length but somewhat longer or shorter than this.

b. The mutual capacitance at the end section of the pair under test may be somewhat larger or smaller than 0.083 microfarads per mile.

c. For existing plant both the pair capacitance at the end section and its physical length can vary from standard values and further the values themselves may be different than present objectives in use.

d. Shortening or lengthening of the end section due to relocations, highway crossings, etc.

e. Minor amounts of moisture or other contamination in the cable end section.

8.52 To assure that the values measured are the best values possible, "maximization" is used. That is, that value of structural return loss is determined which gives the best performance, so to speak, possible from the outside plant. Maximizing the structural return loss is accomplished by means of an external variable capacitor shown as C2 in Figs. 10-19. By this means, such adverse factors as those discussed in paragraph 8.51 (a) to (e) above, which would tend to degrade the value of structural return loss, are eliminated. The actual procedure for accomplishing this is discussed in paragraphs 8.521 to 8.524.

8.521 An additional variable capacitor (shown as capacitor C2 in Figs. 10-19) should be connected across the "Line" terminals of the hybrid, that is, directly across the cable pair. Vary this capacitor. If this improves the SFSRL or ESRL (particularly in the 2500 to 3000 band for SFSRL measurements as discussed in paragraph 8.524 below), this means that the end-section at the hybrid location is electrically shorter than 0.5 though in physical lengths at 0.5. Capacitor C2 should be varied until the optimum value of SRL is obtained and the data recorded in the Data Sheets. Use this value of SRL instead of that obtained in paragraph 8.48 above using the 0.5 end sections.

8.522 If the variable capacitor across the cable pair as discussed in paragraph 8.521 above results in poorer values of SRL for either SFSRL or ESRL measurements (again, particularly in the 2500-3000 cps band for the SFSRL measurements) than the values of paragraph 8.48 above this means that the end-section at the hybrid location is electrically longer than 0.5 though in physical length at 0.5. Remove this capacitor from the "cable" side of the hybrid and connect it to the "net" side of the hybrid, that is directly across PBN No. 1 terminals 1 and 2. This is shown as capacitor C1 in Figs. 10-19. Vary this capacitor (connected across the "net" hybrid terminals) until the optimum value of SRL is obtained and record this value of SRL in the "Data Sheets". Use this value of SRL instead of that obtained in paragraph 8.48 above.

8.523 Finally, if this building-out capacitor connected on the "Line" terminals of the hybrid (across cable) or across the "Net" hybrid terminals (across PBN No. 1) lowers the value of SRL as obtained in paragraph 8.48 above this means that the end-section adjacent to the hybrid is not only 0.5 in length, but also 0.5 electrically (which is really the important consideration) and the SRL values measured in paragraph 8.48 are the optimum values.

8.524 The above procedure for adjusting the end-sections result in obtaining the "best possible" or optimum value of SRL. When making the actual SFSRL measurements, the decision as to "when" the "best possible" or optimum SRL has been obtained will not be one-hundred percent clear cut and some adjustment will be required. This is because each time the value or position (with respect of the hybrid) of the building out capacitor is changed the entire waveshape of the SRL will also change. At some frequencies where the SRL was better, it may now become worse while at other frequencies the reverse will occur. However, at some important range of frequencies the SRL will improve and this is what the CBO procedure is intended to accomplish. In SFSRL measurements this frequency band of interest is the 2500 to 3000 cps range because in a 3 kc/s band, this range would offer the greatest possibility for repeater singing problems. On the other hand, when using this procedure the CBO must not degrade unduly the remaining frequency band from 300 to 2500 cps. For example, this lower band should remain at an SRL level higher than the 2500 to 3000 cps band. Again judgment will be required on this. Experience in making these measurements will make the selection of the optimum condition relatively easy. The above comments are not applicable to the ESRL measurements. There, a given amount and location of CBO will either improve or degrade the return loss. The CBO resulting in the best ESRL should, of course, be recorded.

8.6 Location Which is Controlling on the Measurement

8.61 The effect of the far-end PBN (or No. 2 PBN) normally is not as controlling on the values of the SRL which are measured at the sending-end. This is because the attenuation tends to mask small irregularities at the far end as a result of PBN No. 2 not precisely matching the cable end-section at that end and by the time this small irregularity arrives at the sending-end its value is high so that it does not change the value of SRL in any significant way. The above holds only when the circuit attenuation is substantial, 8 to 10 db or higher. If the circuit attenuation, however, is 5 to 8 db or lower the far-end will effect the sending-end SRL. For this reason, the CBO at the PBN No. 2 location (shown as CBO2 in the H-88 examples and C3 in the D-66 examples) must be varied also until the optimum SRL is obtained at the sending-end. Regardless of the circuit attenuation, it is advisable at the end of the measurement steps discussed in paragraphs 8.4 to 8.5 above to vary the C3 (or CBO2 for H-88 loading) at the far-end until the optimum SRL has been obtained at the sending-end. This optimum SRL is the SRL values which should be recorded in the "Data Sheets". It is obvious, of course, that if the measurement location is reversed, the far-end section PBN which was not of extreme importance before will now be the controlling factor. The above considerations are applicable equally to SFSRL and ESRL measurements.

8.7 Treatment of Mixed Cable Gauges

8.71 Cables which are uniform in gauge, that is, all 22-gauge D-66 or all 19-gauge H-88, etc., for the entire circuit length will be much easier to measure for SRL than cables of mixed gauges. The measurement of mixed gauges is discussed in paragraph 8.72 below. For uniform gauge cables the only adjustment which may be required during the measurement will be in the capacitance of the end-section adjacent to the hybrid location resulting in the "optimum" value of SRL for the particular cable under test. The procedure for accomplishing this is discussed below.

8.72 Due to the measuring complexity which mixed gauges present, it is recommended that when the measurement is made the PBN gauge settings be changed alternately from one gauge to the next starting with the sending-end PBN and then with the far-end PBN until the combination in gauges is found which yields the optimum SRL which is possible for the particular layout. This procedure applies equally to SFSRL and ESRL measurements.

8.8 Use of Level Tracer Equipment

8.81 Where the cable to be measured consists of only one uniform gauge and where the end-sections are close to 0.5 in length it will be found that the measurement becomes relatively simple using the single frequency techniques and the test equipment shown in Figs. 10-14 herein. Where the end-sections are longer or shorter than 0.5 and/or where mixed gauges are involved the measurement complexity and the time required increases. This is because especially with SFSRL or point-by-point measurement techniques each time a change is made, for example, in end-section CBO, PBN gauge, etc., the entire frequency band must be plotted and the comparison made to see if this change has improved the SRL. Thus, for SRL measurements the major disadvantage becomes one of time, but the results of point-by-point measurements are nevertheless valid.

8.82 The above type of SFSRL measurements become relatively simple if swept-band type oscilloscopes are available for use. These devices allow the entire band to be observed at a glance. The result of any-one adjustment or adjustments during the measurement procedure can be immediately seen and analyzed. Thus, the conditions which give optimum SRL can now be accurately pinpointed. Because such swept-band devices greatly facilitate measurements they should be used whenever they are available. The Siemens-Halske Rel 3K 211b Level Tracer of the Lear/Siegler Swept-Band Oscilloscopes can be used with good results. Typical measurement examples when using the Siemens-Halske Level Tracer are shown in Figure 35.

8.9 Other Important Considerations

8.91 The structural return loss measurements must be made at the location where the repeater equipment will normally be located and operated. For example, in a toll connecting trunk application where the terminal repeater will be located at the Class-5 office, the structural return loss measurement must be made from that office. That is the test hybrid must be located at the office where the repeater will be located. Where repeaters will be located at each of two terminal offices measurements must be made from each office for the same cable. In intermediate repeater applications the measurements must be made from the repeater location but looking in each cable direction.

8.911 It is advisable that measurements on the same cable be made in each direction. This helps detect irregularities which may still be present but which the measurement from one end only may not reveal. This comes about from the intervening circuit attenuation. If the attenuation is appreciable, say 12 db at 2800 cps, the round-trip circuit attenuation will be at least 24 db, even though the far-circuit end may be open or shorted, and this will also be the minimum value of SRL at the measuring end. In other words, if an irregularity exists which is far from the point of measurement the intervening attenuation will mask it and reflect it as a fairly good value of SRL at the measuring point. To assure against this occurring if the measurement is now made from the opposite end, the value of SRL will be much lower (less masking attenuation) and thus much easier to detect.

8.92 Prior to making measurements on D-66/H-88 loaded cables joined by the D-66/H-88 junction impedance compensator (For the configuration of the junction compensator refer to REA TE & CM-431, Fig. 1) assure by checking that the compensation is properly designed and correctly inserted into the cables. That is, that the proper value of building-out capacitors for the D-66 and H-88 sides have been provided and that the D-66 terminals of the compensator are connected to the D-66 loaded cable and the H-88 compensator terminals to the H-88 cable. Also inspect the connections to determine that no pairs have been split. These checks are in addition to the CBO and gauge considerations discussed in the above paragraphs.

9. EXPECTED MEASURED PERFORMANCE

9.1 Field measurement data have substantiated the structural return loss performance on which the D-66 design has been predicated. Where more than routine care has been taken to design, stake and build the plant this is also reflected in SRL's exceeding the minimum expected values. Where the cable is of one single uniform gauge this also results in higher values of SRL. Lastly, where the cable consists of one gauge and one size (for example, 25 pair, 22 gauge for the entire circuit length) this produces the highest value of SRL possible. This is because in plastic color coded cables like numbered pairs of like gauge and like size tend to have the least amount of mutual capacitance deviation from one reel to another (for the same manufacturer). For this reason with color-to-color splicing of the same numbered pairs in the same binder groups this results in uniform capacitance between each loading section which in turn results in higher than normal values of SRL.

9.2 For cables which are uniform gauge D-66 loaded for their entire length and which meet the load spacing deviations of Section 431, "Voice Frequency Loading For Trunk Cables", paragraphs 3.4 and 3.5 and the cable mutual capacitance deviation requirements in the REA PE Cable specifications, a minimum value of 25 db SFSRL at the critical frequency (CFSRL) and 32 db ESRL minimum are expected.

9.3 For cables which are uniform gauge D-66 loaded for their entire length and where the load spacing is better than the minimum requirements of Section 431, paragraphs 3.4 or 3.5 and/or where a single gauge and single size is used, values of 30 to as much as 35 db CFSRL can be expected as minimum values (worse values) and 42 db ESRL.

9.4 D-66 loaded cables measuring 22 db or less for CFSRL contain significant irregularities and require corrective action. Though for a particular application a value of 22 db CFSRL may be adequate, the outside plant facilities nevertheless do not meet the standards to which they have been engineered.

9.5 Illustrative cases shown in Figs. 20-30 indicate values of SFSRL on D-66 loaded cables which have been measured in REA borrowers' systems and which are considered typical. These examples are illustrative of the performance which can be expected upon measurement for the various conditions discussed in paragraphs 9.1 to 9.3 above.

10. DATA SHEETS FOR RECORDING MEASUREMENTS

10.1 The forms used to record the SFSRL and ESRL measurements and the other information which is required are shown in "Data Sheet - Structural Return Loss Measurements"

10.2 When making the measurements, it is essential that the outside plant facility configuration be accurately known, including the manner by which the measurements have been carried out and any adjustments which have been found necessary. This information is necessary in order to analyze the results and determine whether the objectives are being met or whether corrective action is required. Besides serving as a record for initial acceptance measurements, it also provides the plant forces with a powerful tool for performing routine testing on these circuits or for correcting problems should they occur. It is extremely difficult to evaluate results of transmission measurements, to make recommendations for correction of transmission problems or to perform routine testing when plant and/or test records are lacking or incomplete.

11. ANALYSIS OF RESULTS IN FIGURES 20-35

11.1 (Fig. 20) The worst value of single frequency structural return loss (CFSRL) for this layout is 35.2 db at approximately 2390 cps in the 300-3000 cps band, thereafter called "3000 cycle band" and the echo structural return loss (ESRL) is 41.0 db. The reason for this good performance is due to (a) the load spacing deviation of the as-built plant being 0.3 percent (b) the cable mutual capacitance measured between loading points being very nearly 0.083 microfarads per mile and (c) uniform gauge. Factors (a) and (b) above are the more important ones. Because the consulting engineer for this project was aware of the importance of good loading and implemented this through his resident engineer on the job by exercising extra care in locating the loading points very accurately, the SRL is as good as it can be obtained. Thus, it pays to do a better than routine job whenever this is possible. There is one other important observation in the SRL in this layout. This is that the CFSRL in a 3400 cps band is also very good at 33.5 db. This comes about, again, from the good spacing but also because the capacitance of this pair is uniformly 0.083 mf. Whenever the pair mutual capacitance is uniformly .083 microfarads per mile for the entire cable route of very high SRL values should be expected not only in the 3000 cycle band but even up to 4000 cps. For example, at 4000 cps the SRL of this pair is 31.3 db and this is quite good.

11.02 (Fig. 21) This is a different pair in the same cable and trunk group as the pair shown in Fig. 20. The 3000 cycle band CFSRL is 30.3 db and the ESRL 35.5 db. The SRL for this pair also reflects the care given for obtaining good load spacing. The reason that this pair has a 5 db (approximately) lower CFSRL compared with the pair in Fig. 20 is because the mutual capacitance in this pair is slightly different than 0.083 microfarads per mile. Therefore it has a lesser value of CFSRL. However, this is entirely normal. In a group of pairs (in the same cable sheath and the same trunk group) having unusually high values of SRL the differences in the values between the different pairs will normally be large. This is because the SRL is already so high that even very small deviations become important. It should also be noted that the SRL for this pair stays very good even up to 4000 cps.

11.03 (Fig. 22) The SRL for this pair is very good up to about 2600 cps but it becomes rapidly worse at frequencies higher than this. This is despite the good load spacing in this cable route. The reason for this is that the cable pair in question was measured and found to have a capacitance of approximately 0.087 microfarads per mile (instead of the desired 0.083 value) but this capacitance was uniform for the entire cable route. This makes the return loss at the higher frequencies to be not as good as the lower frequency values. It can also be noted that the ESRL remains very high at 40.5 db. This is because the echo band as discussed in paragraph 4.72 above is between 500 to 2500 cycles and in this frequency region the SRL is very good despite the higher than normal capacitance of this cable pair. The CFSRL is 30.2 db up to 3000 cps. This meets the objective and is actually better than the objective. Thus, with the D-66 loading system, if the load spacing is good, even pairs with higher mutual capacitance than that desired can still give good values of structural return loss in a 3000 cps band if the cable capacitance remains uniformly high for the entire cable route.

11.04 (Fig. 23) In this figure the SRL of the same pair shown in Fig. 22 is shown but measured from the opposite office. It is now seen by comparing Figs. 22 and 23 that the SRL values are not the same. They should not be expected to be the same. The irregularities in a loaded cable will normally be different when viewed from the opposite circuit ends. The values of their CFSRL, however, should be comparable. In the 3000 cycle band the difference is 3.2 db (33.4 -30.2 db) and this is considered normal. This figure also shows the effect of building out capacitance. For example, by placing the 0.009 microfarad capacitor to build out the 3912 foot section, the SRL is improved considerably above 2200 cps. This improvement is 6 db at 2500

cps and 2.3 db at 3000 cps. Therefore, if capacitance building out is not used where needed the resulting SRL will be lower than that which can be realized.

11.05 (Figs. 24-25) The same pair is measured in these figures but from opposite directions. It is seen that the waveshape is not the same, again, because the irregularity is not the same in each direction of transmission. However, the critical values are close enough so that they can be considered to be within the normal range of variation. In Fig. 24 the CFSRL is 30.3 db, whereas in Fig. 25 it is 31.0 db. However, whereas in Fig. 24 the CFSRL is at about 2660 cps, in Fig. 25 it is at 3100 cps and this is also considered normal. The CFSRL values meet the objectives when measured from each office.

11.06 (Fig. 26) The SRL is very high up to about 2600 cps but this pattern is not maintained for frequencies higher than this. This is despite the good load spacing, the uniform gauge and the uniform size of the cable. This can be explained by the 0.088 microfarad per mile mutual capacitance for this pair for the entire route which is higher than the desired value of .083. However, because the D-66 loading has a wide band, this affect does not begin to show until frequencies of 3000 cps or higher. Thus, very good SRL values are obtained in this band despite the high capacitance of the cable pair. The 3000 cycle band CFSRL is 29.5 db and this is considered quite good.

11.07 (Figs. 27-28) In Figs. 27 and 28 it is shown what can be expected as the worst values of CFSRL with D-66 loading when the pair capacitance is higher than the desired .083 microfarads per mile, but is uniformly high at this value for the entire route and when the load spacing is also good. It can be seen that the respective CFSRL values are 26.8 and 27.3 db and these are about the worst values which should be expected. The ESRL values are 36.0 and 38.0 db and these values should be considered typical for D-66 loading under the conditions indicated.

11.08 (Figs. 29-30) These are illustrative of what can be expected with mixed gauges. The CFSRL values are much lower than the values in the previous figures for uniform gauge. For example, the respective CFSRL values are 25.5 and 25.6 db. The critical frequency is now at the low end of the band at 300 cps. Because the precision balancing net is set for one particular gauge only it is not possible to match the many gauges in the outside plant. What therefore results is a compromise value of SRL. The higher frequency SRL, starting at frequencies higher than 2000 cps, is not affected by the mixture of gauges. Mixing the different gauges affects frequencies lower than 1000 cycles and especially around 300 cps. The reason that the high frequency SRL is not as good is because of the different values of capacitance in the loading sections. For the pairs shown some sections measured were found to have a mutual capacitance lower than the desired value of .083 microfarads per mile while others had higher capacitance than this. Thus, the mutual capacitance value is not uniform throughout the cable route. For this reason the high frequency CFSRL for these pairs is not nearly as good as for the pairs in the previous figures. There the capacitance was higher than .083 microfarads per mile but this value was uniformly the same for the entire cable route.

11.09 (Fig. 31) This H-88 loaded pair is typical of what can be expected in an H-88 loaded system which has (a) close to ideal end-sections (b) reference spacing deviation better than .5 percent (c) uniform gauge (d) RMS cable capacitance deviation of 1.7 percent and (e) random splicing. The CFSRL is 22.5 db at 1600 cps in a 3000 cps band. It should be noted that the SRL of the cable becomes extremely poor at frequencies higher than 3000 cps but this is typical of H-88 loading.

11.10 (Fig. 32) This figure is representative of H-88 loading having (a) mixed gauges and (b) one long full section (6229 feet). The CFSRL value is 18.3 db. This is 7.3 db worse than the example in Fig. 29 which also has mixed gauges and also large variation in capacitance but which is D-66 loaded.

11.11 (Fig. 33) In this layout the loading points have been spaced with extreme precision so that the load spacing deviation is close to zero and the gauge is uniform. Therefore, the SRL in this layout is representative of what should be expected of an "ideally spaced" H-88 loaded system. The CFSRL is 25.6 db at 2990 cps in a 3000 cycle band which is exceptionally good. It should be noted that the SRL drops rapidly at frequencies higher than 3000 cps and this is to be expected because this is a basic characteristic of this loading system.

11.12 (Fig. 34) This layout is representative of what can be expected in a D-66/H-88 loaded system joined with the D-66/H-88 junction impedance compensator. The CFSRL is 23.0 db. This is not as high as the D-66 examples shown in the previous figures. The reason for this lower value is because it connects with the H-88 loading system and the H-88 becomes the controlling factor. For such compensated layouts the 23 db CFSRL values can be considered acceptable.

11.13 (Fig. 35) Four different layouts are shown in this figure measured with the Siemens-Halske Level Tracer type Rel 3K 211b for D-66 and H-88 loaded cables. The curves are read as follows: At any particular frequency the db's on the vertical axis are read. To this the received level value is added algebraically. As an example, in the fourth layout the SFSRL value at 2000 cps is:

Vertical Axis:	- 5 db
Receive :	-20 db
Algebraic Sum:	-25 db

Therefore the SRL at this frequency is 25 db.

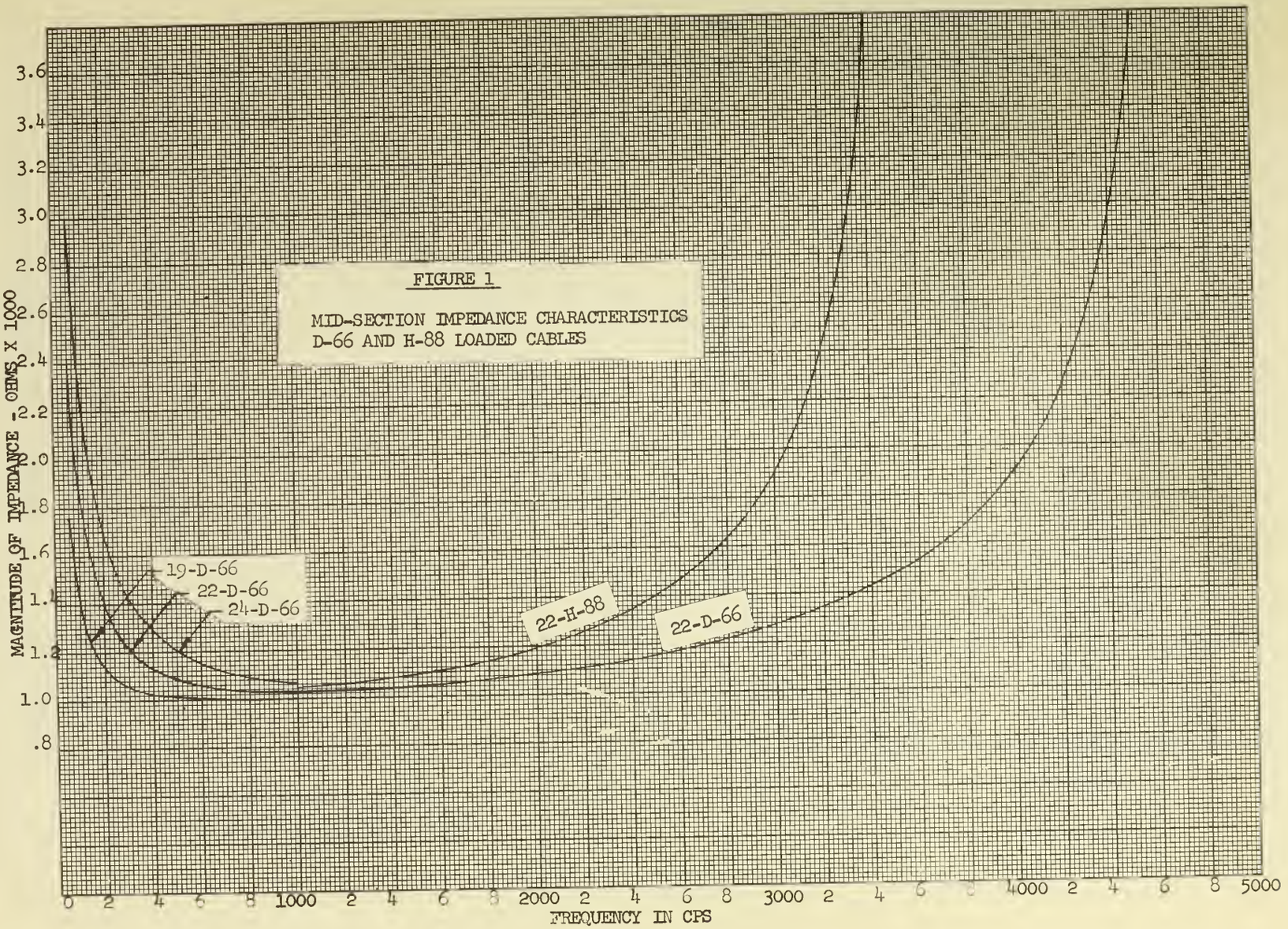


FIGURE 1
MID-SECTION IMPEDANCE CHARACTERISTICS
D-66 AND H-88 LOADED CABLES
MAGNITUDE OF IMPEDANCE - OHMS X 1000
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
19-D-66
22-D-66
24-D-66
22-H-88
22-D-66
0 2 4 6 8 1000 2 4 6 8 2000 2 4 6 8 3000 2 4 6 8 4000 2 4 6 8 5000
FREQUENCY IN CPS

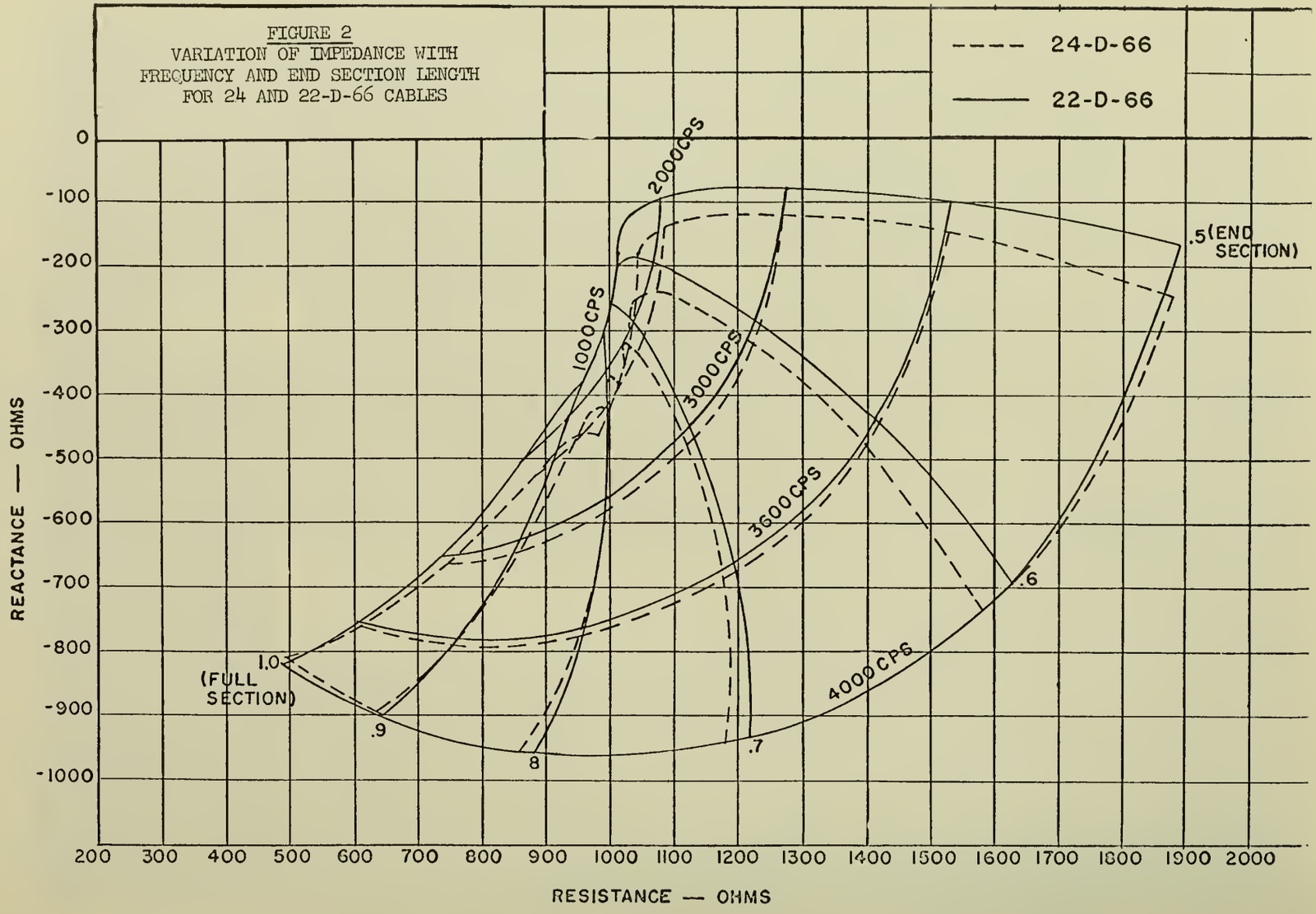
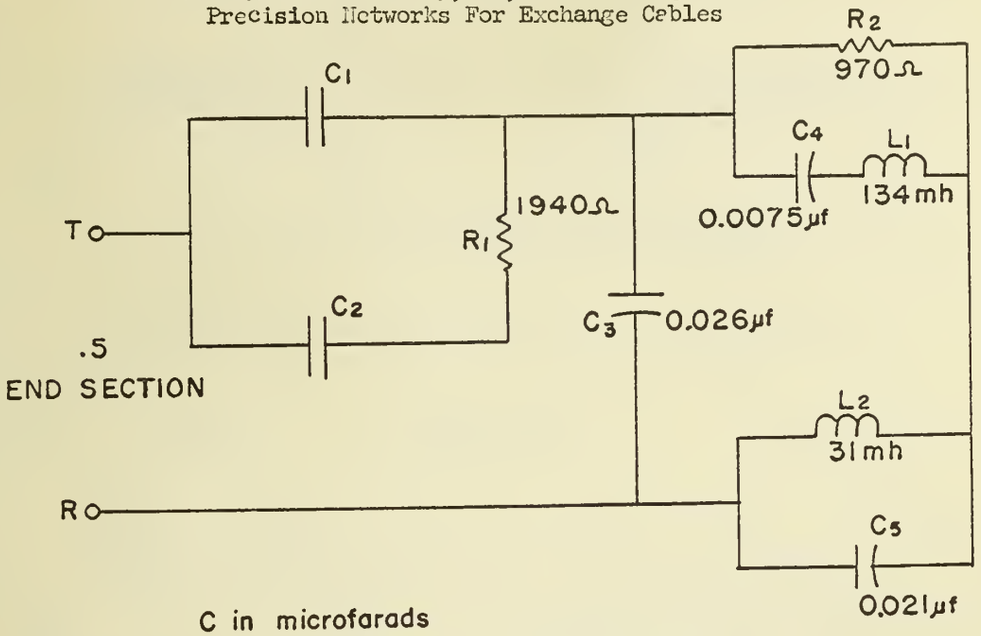


FIGURE 2
VARIATION OF IMPEDANCE WITH
FREQUENCY AND END SECTION LENGTH
FOR 24 AND 22-D-66 CABLES
24-D-66
22-D-66
REACTANCE — OHMS
RESISTANCE — OHMS
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
2000CPS
1000CPS
3000CPS
3600CPS
4000CPS
1.0
(FULL
SECTION)
.9
.8
.7
.6
.5(END
SECTION)

FIGURE 3

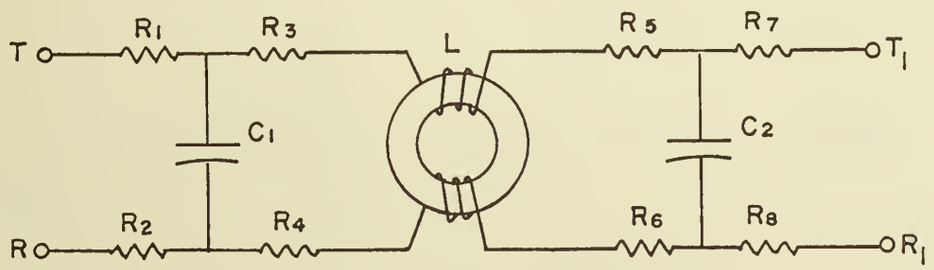
Configuration for 19, 22, and 24 Gauge D-66
Precision Networks For Exchange Cables



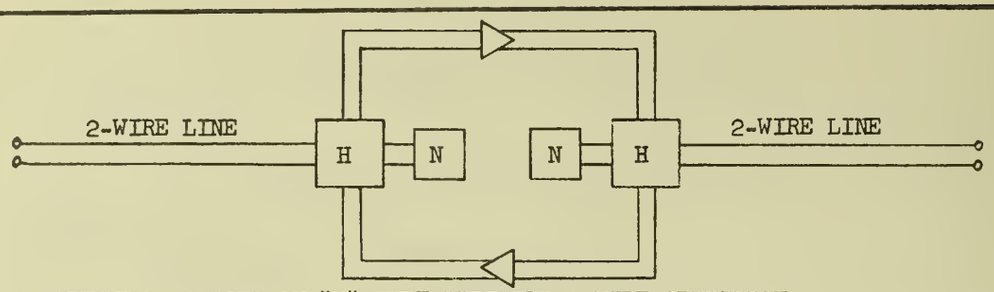
C in microfarads

19 GAUGE	22 GAUGE	24 GAUGE
$C_1 = 1.686$	$C_1 = 0.936$	$C_1 = 0.585$
$C_2 = 2.310$	$C_2 = 1.070$	$C_2 = 0.715$

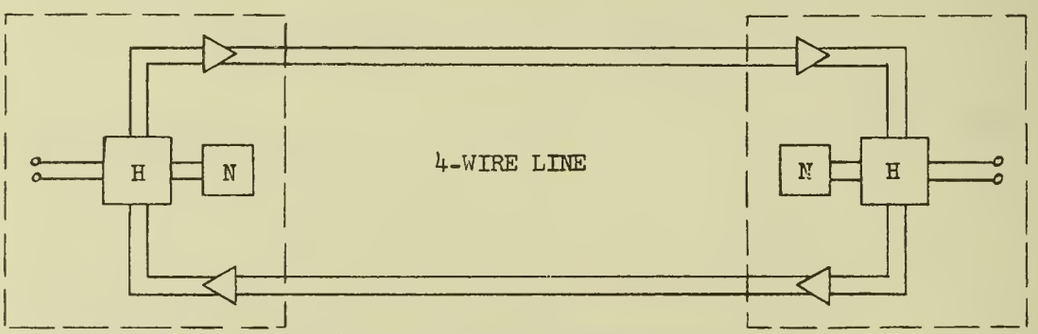
Configuration for 19, 22, and 24 Gauge
D-66 Artificial Loaded Lines



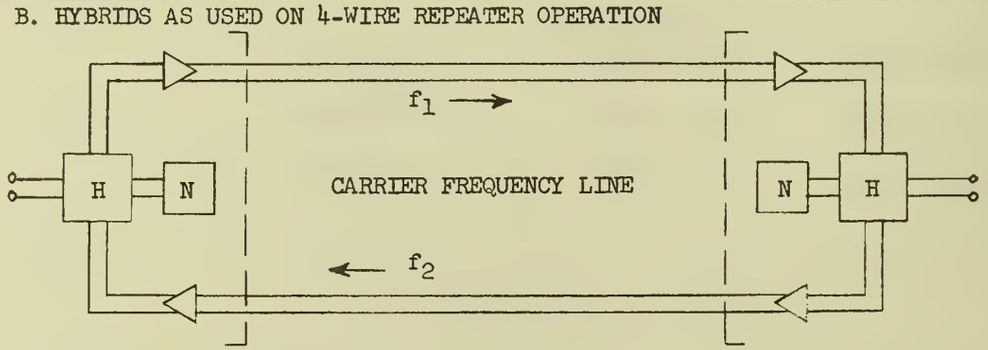
	19 GAUGE	22 GAUGE	24 GAUGE
R_{1-8}	9.05Ω	18.2Ω	29.2Ω
L	66mh	66mh	66mh
$C_{1,2}$	0.03535μf	0.03535μf	0.03535μf



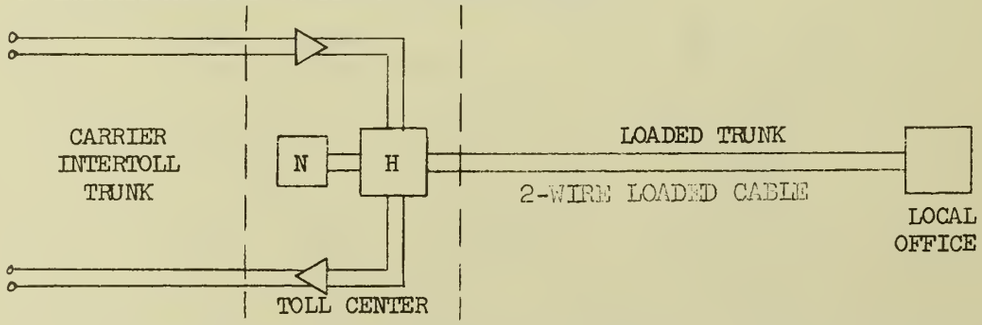
A. HYBRIDS AS USED ON "V" TYPE REPEATER 2-WIRE OPERATION



B. HYBRIDS AS USED ON 4-WIRE REPEATER OPERATION

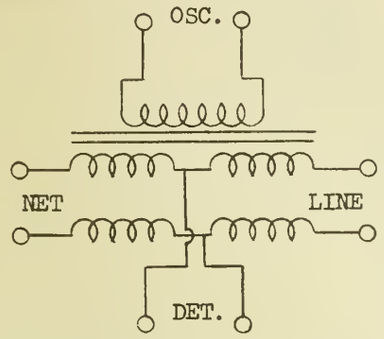


C. HYBRIDS AS USED ON TYPICAL CARRIER SYSTEM

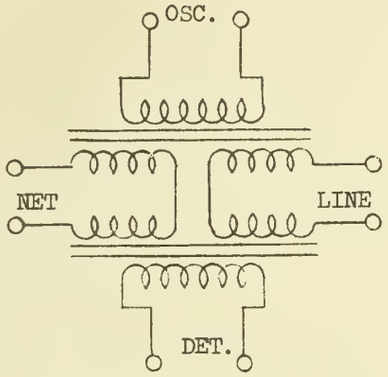


D. 4-WIRE TERMINATING SET AS USED AT TOLL CENTER TO CONNECT INTERTOLL TO TOLL CONNECTING TRUNK

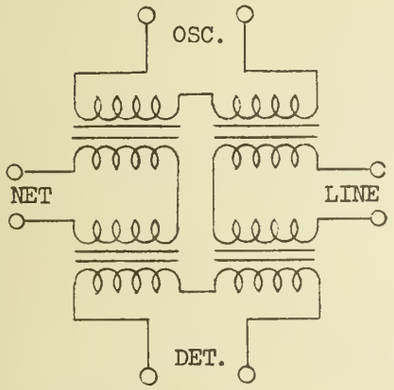
FIGURE 5 TYPICAL APPLICATIONS WHERE HYBRIDS ARE USED



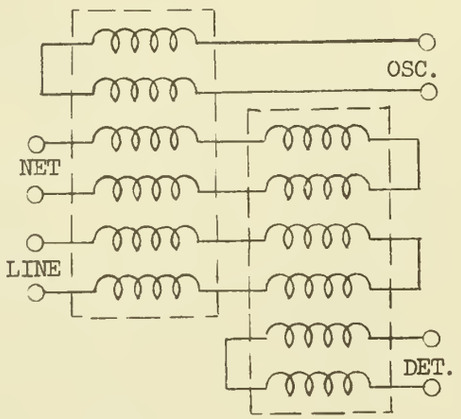
A. ONE-COIL HYBRID



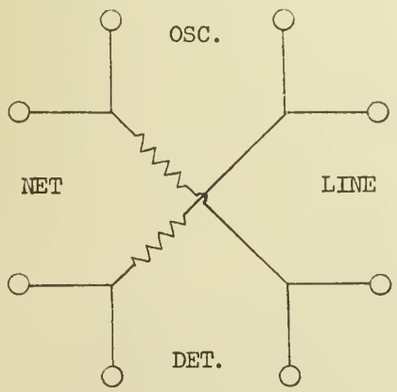
B. TWO-COIL HYBRID



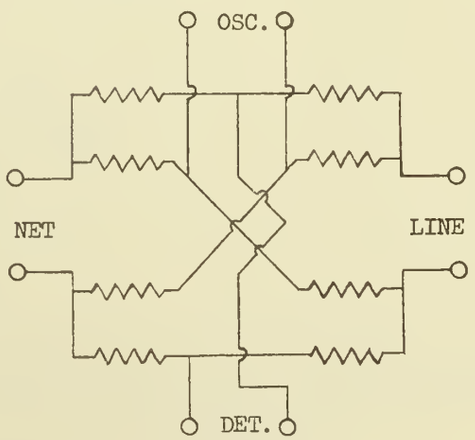
C. FOUR-COIL HYBRID



D. 6-WINDING HYBRID

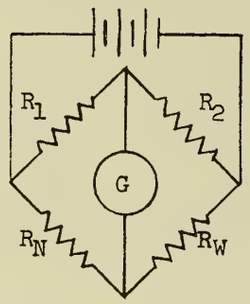


E. RESISTANCE HYBRID

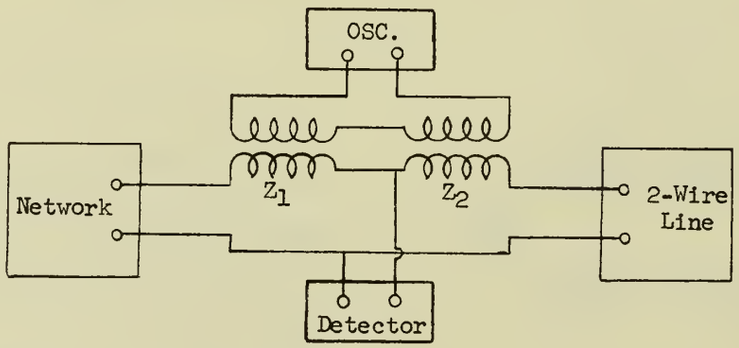


F. RESISTANCE HYBRID

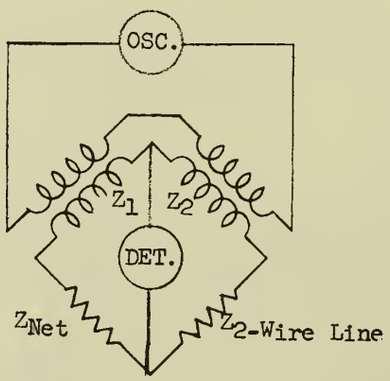
FIGURE 6 VARIOUS TYPES OF COIL AND RESISTANCE HYBRIDS



A. Conventional D.C. Wheatstone Bridge Circuit



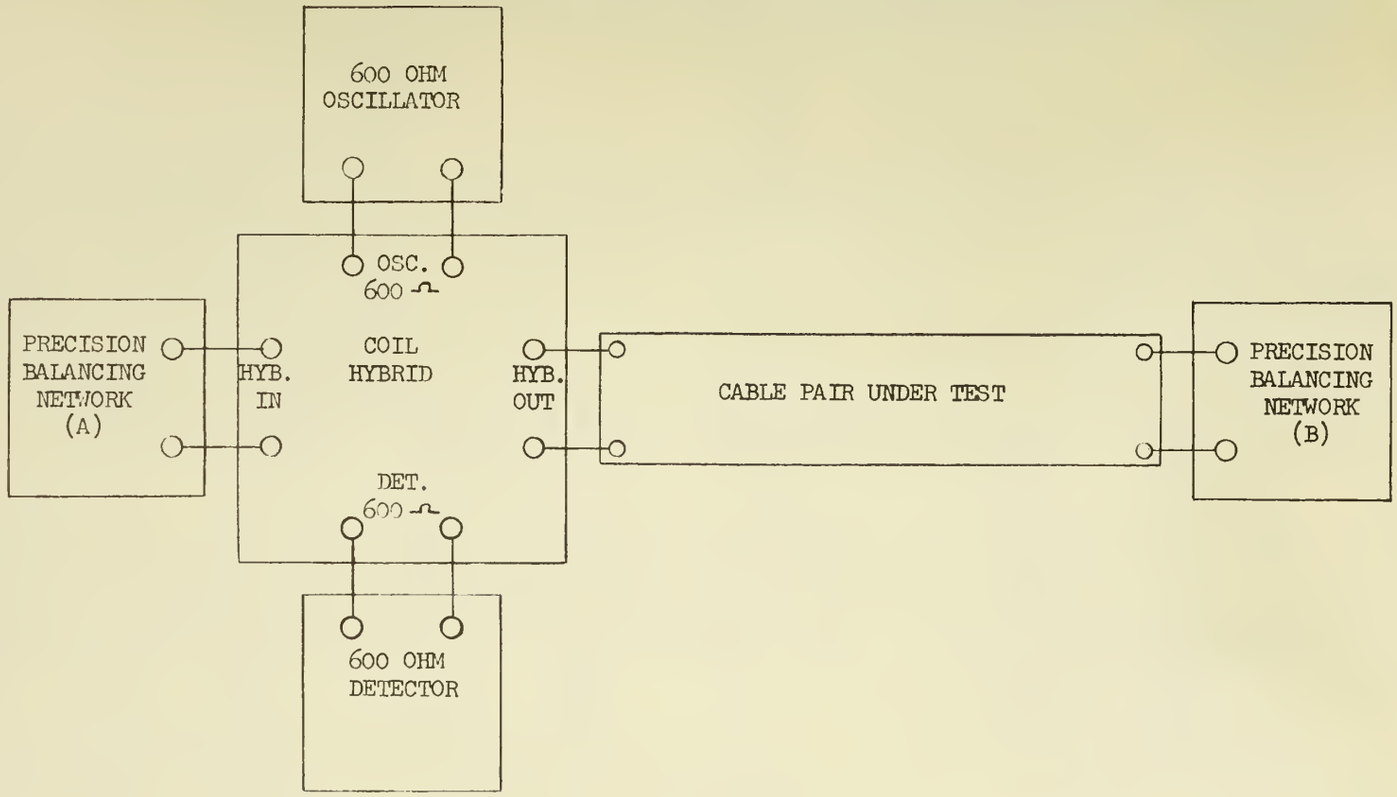
B. Simplified Coil Type Hybrid



C. Coil Hybrid of (B) above redrawn on a Wheatstone Bridge Basis

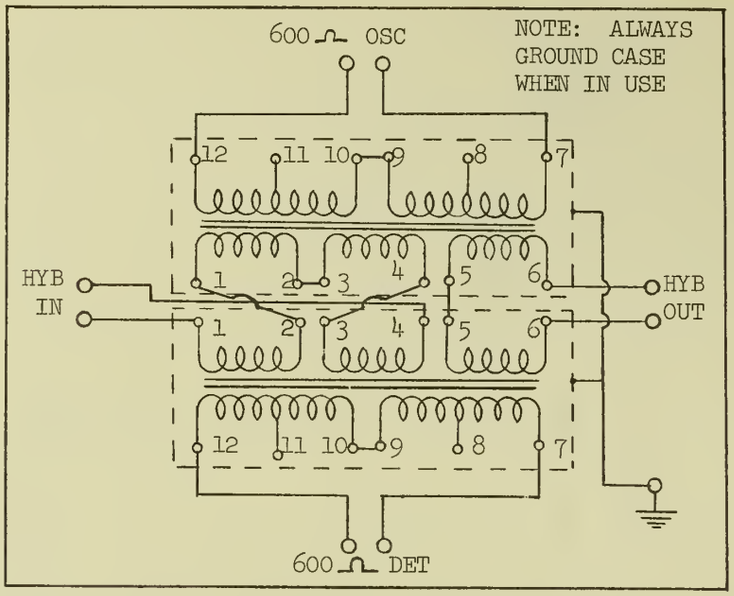
THE HYBRID AS AN ANALOGY TO THE WHEATSTONE BRIDGE

FIGURE 7

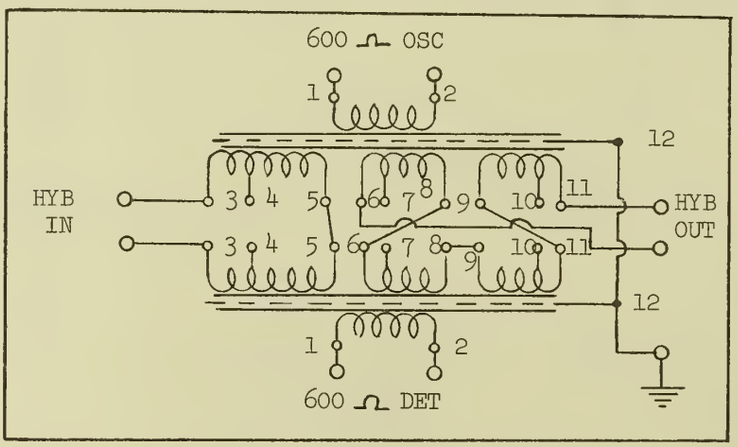


BASIC DIAGRAM FOR THE SRL MEASUREMENT

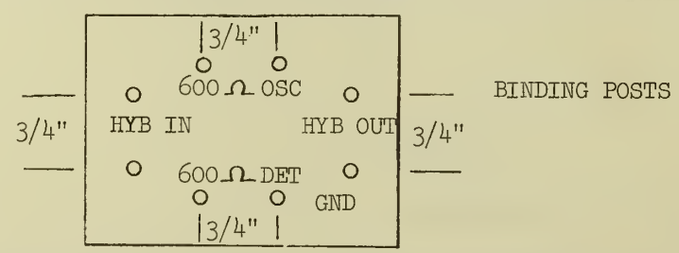
FIGURE 8



WIRING DIAGRAM OF TWO W.E. CO. 120P REPEATING COILS USED TO FORM A HYBRID



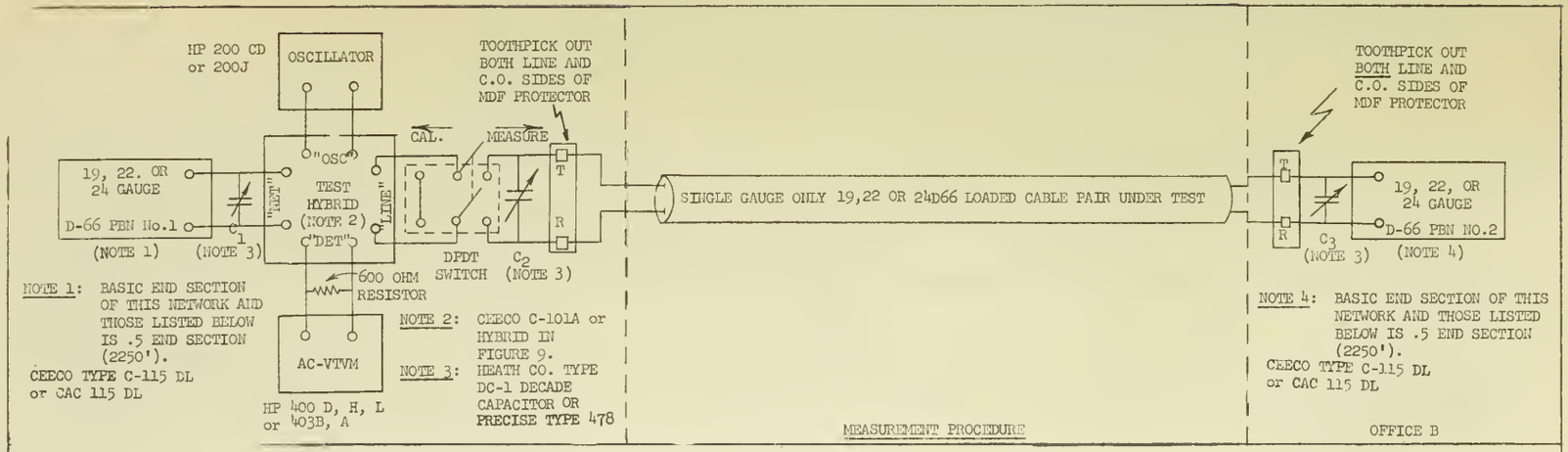
WIRING DIAGRAM OF TWO ALTEC LANSING 15189 REPEATING COILS USED TO FORM A HYBRID



SUGGESTED PHYSICAL LAYOUT OF HYBRID FACEPLATE

WIRING DIAGRAMS FOR THE CONSTRUCTION OF TEST COIL HYBRIDS

FIGURE 9



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Connect the test equipment and cable pair under test as shown above. Be sure to strap or set PBN "gauge terminals" for same gauge as gauge of cable being measured.

2. Throw DPDT switch to "CALIBRATE" position. Set oscillator frequency to 2000 cps and vary output level until A.C.-VTVM reads 0 dbm (zero dbm); this completes calibration. Throw DPDT switch to "MEASURE" position. Do not change oscillator output level control. Set C_2 to build-out cable end section to 2250' total.

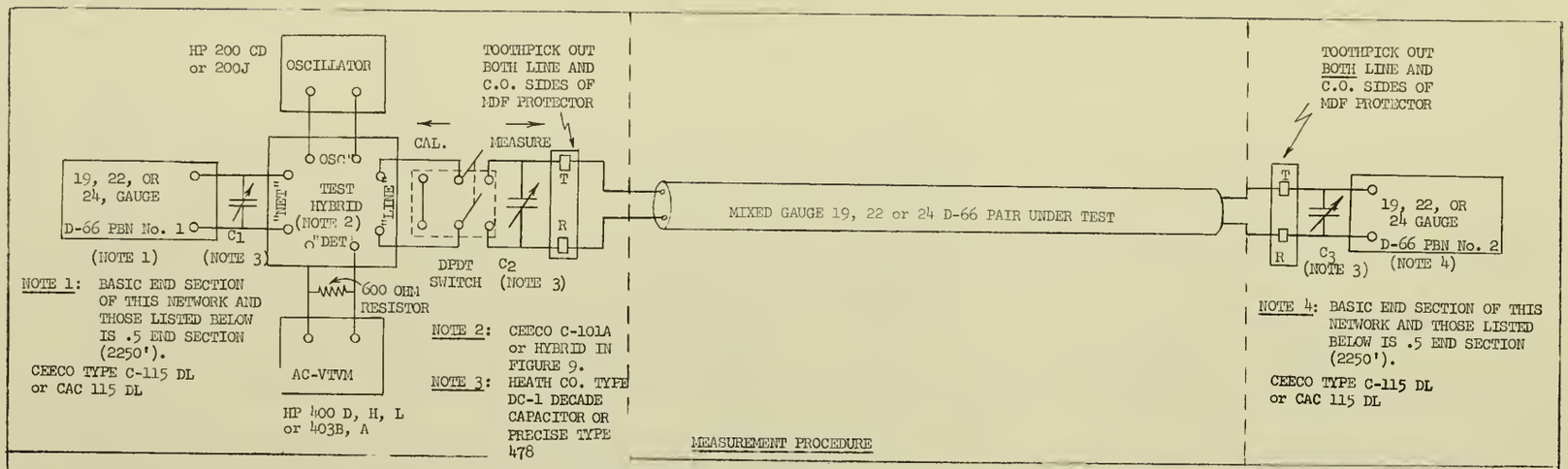
3. Vary oscillator frequency vernier, slowly, between 200 to 4500 cps and note the frequencies which give consecutive maximum (peak) and minimum (valley) readings on the A.C.-VTVM. Read each peak and valley frequency and the minus dbm reading on the A.C.-VTVM corresponding to each and enter the results in the "Data Sheets—Structural Return Loss Measurements."

4. Increase value of C_2 from that in step (2) and repeat step (3). Note whether SRL becomes better or worse particularly between 2500 to 3000 cps (SRL becomes better as readings in A.C.-VTVM get more negative.) If SRL gets better this means that end section is electrically less than 2250 feet (though by length alone it is 2250 feet). Vary C_2 until the value is found that gives the best SRL (especially between 2500 to 3000 cps).

5. If by increasing C_2 in step (4), SRL gets worse, this means that the cable end section is longer than 2250 feet electrically. Return C_2 to its original value in step (2) (to give 2250 feet end-section total). Increase C_1 until the best possible SRL is obtained (especially between 2500 to 3000 cps). Record the results in the "Data Sheet—SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING. Record also the SRL value at 3400 cps.

6. If by increasing C_1 or C_2 SRL gets worse, this means that the end section as built out in step (2) to 2250 feet is not only 2250 feet in length but also 2250 feet electrically, which is the important thing. If this is the case, continue with the measurement as per item (3) and record the data in the "Data Sheet—Structural Return Loss Measurements."

FIGURE 10. SINGLE FREQUENCY STRUCTURAL RETURN LOSS MEASUREMENT OF ONE UNIFORM GAUGE ONLY FOR ENTIRE CIRCUIT LENGTH (19, 22 OR 24-D-66)



MEASUREMENT PROCEDURE

DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Connect the test equipment and cable pair under test as shown above. Set gauge of PBN No. 1 for most predominant gauge adjacent to hybrid and PBN No. 2 for most predominant gauge adjacent to it.

2. Throw DPDT switch to "CALIBRATE" position. Set oscillator frequency to 2000 cps and vary output level control until A.C.-VTVM reads 0 dbm (zero dbm); this completes calibration. Do not change oscillator output level control. Throw DPDT switch to "MEASURE" position. Set C_2 to build-out cable end section to 2250' total.

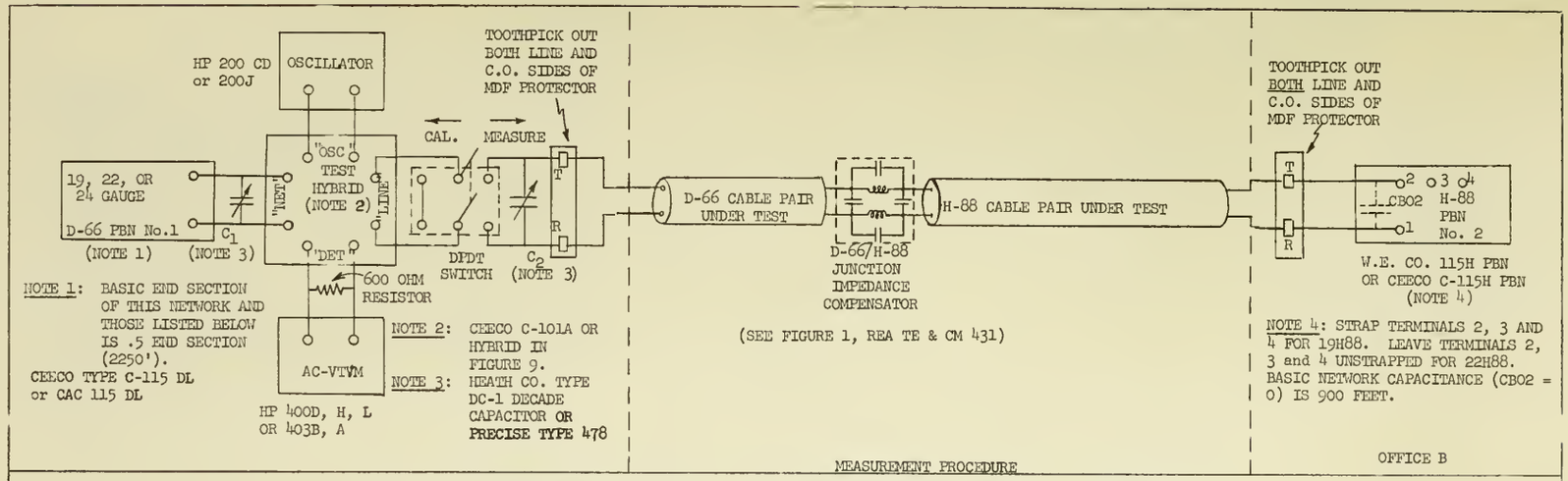
3. Vary oscillator frequency vernier, slowly, between 200 to 4500 cps and note the frequencies which give consecutive maximum (peak) and minimum (valley) readings on the A.C.-VTVM. Read each peak and valley frequency and the minus dbm reading on the A.C.-VTVM corresponding to each. Change gauge of PBN No. 1 (if it is set for 19 gauge in step (1), change it to 22 or 24) and note if this improves the SRL. If it does, leave set for new gauge setting; if not, change back to original gauge. Change gauge of PBN No. 2 from that in step (1) and note if this improves SRL. If it does, leave set for new gauge setting; if not, change back to original gauge. (VARYING GAUGE OF PBN NOS. 1 AND 2 ALTERNATELY WILL BE NECESSARY, DEPENDING ON ACTUAL CABLE LAYOUT, TO OBTAIN BEST SRL.) Record best SRL in the "Data Sheet--Structural Return Loss Measurements."

4. Increase value of C_2 from that in step (2) and repeat step (3). Note whether SRL becomes better or worse particularly between 2500 to 3000 cps (SRL becomes better as readings in A.C.-VTVM get more negative.) If SRL gets better this means that end section is electrically less than 2250 feet (though by length along it is 2250 feet). Vary C_2 until the value is found that gives the best SRL (especially between 2500 to 3000 cps).

5. If by increasing C_2 in step (4), SRL gets worse, this means that the cable end section is longer than 2250 feet electrically. Return C_2 to its original value in step (2) (to give 2250 feet end-section total). Increase C_1 until the best possible SRL is obtained (especially between 2500 to 3000 cps). Record the results in the "Data Sheet--SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING. Record also the SRL value at 3400 cps.

6. If by increasing C_1 or C_2 SRL gets worse, this means that the end section as built out in step (2) to 2250 feet is not only 2250 feet in length but also 2250 feet electrically, which is the important thing. If this is the case, continue with the measurement as per item (3) and record the data in the "Data Sheet--Structural Return Loss Measurements."

FIGURE 11. SINGLE FREQUENCY STRUCTURAL RETURN LOSS MEASUREMENT OF D-66 LOADED CABLES WITH MIXED 19, 22 or 24 GAUGES



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

Measuring at the D-66 end

1. If gauge is uniform, that is, all 19-gauge or all 22-gauge for both the D-66 and H-88, use the measurement procedure of Figure 10,

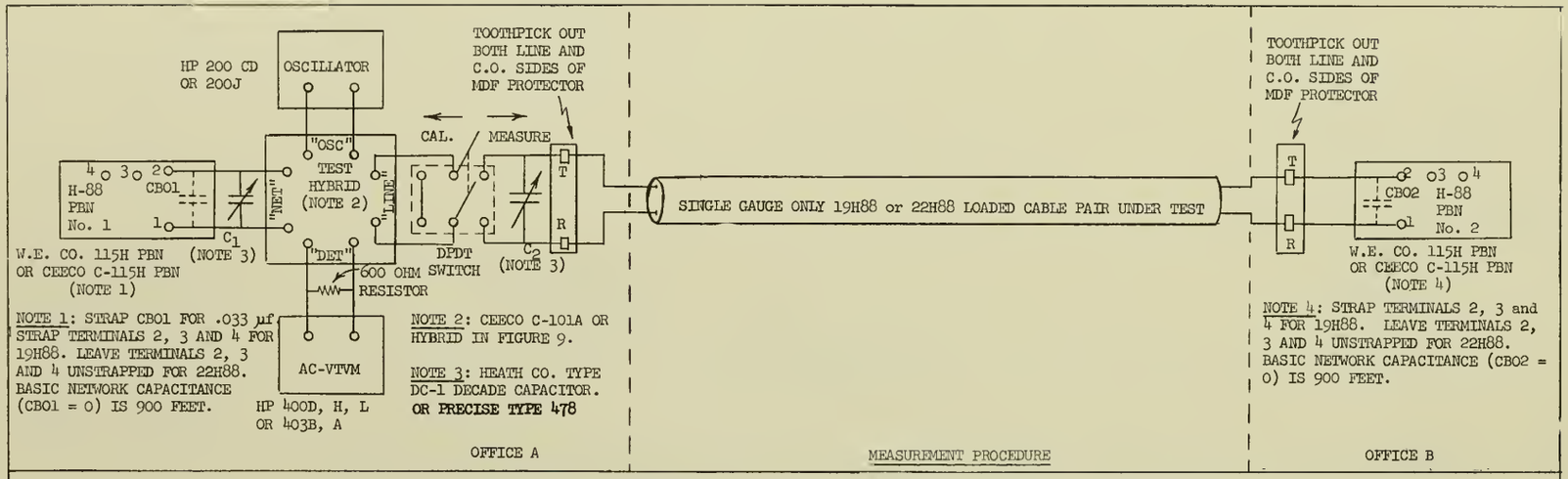
2. If gauges are mixed, used measurement procedure of Figure 11.

Measuring at the H-88 end

3. If gauge is uniform, that is, all 19-gauge or all 22-gauge for both the D-66 and H-88, use the measurement procedure of Figure 13.

4. If gauges are mixed, use measurement procedure of Figure 14.

FIGURE 12. SINGLE FREQUENCY STRUCTURAL RETURN LOSS MEASUREMENT OF D-66/H-88 LOADED CABLES USING THE D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR


HP 200 CD OR 200J
OSCILLATOR
TOOTHPICK OUT BOTH LINE AND C.O. SIDES OF MDF PROTECTOR
CAL.
MEASURE
"OSC"
TEST HYBRID (NOTE 2)
"NET"
"LINE"
"DET"
H-88 PBN No. 1
CB01
C_1
W.E. CO. 115H PBN OR CEECO C-115H PBN (NOTE 1)
600 OHM RESISTOR
DPDT SWITCH
C_2 (NOTE 3)
T
R
SINGLE GAUGE ONLY 19H88 or 22H88 LOADED CABLE PAIR UNDER TEST
TOOTHPICK OUT BOTH LINE AND C.O. SIDES OF MDF PROTECTOR
CB02
H-88 PBN No. 2
W.E. CO. 115H PBN OR CEECO C-115H PBN (NOTE 4)
NOTE 1: STRAP CB01 FOR .033 μf STRAP TERMINALS 2, 3 AND 4 FOR 19H88. LEAVE TERMINALS 2, 3 AND 4 UNSTRAPPED FOR 22H88. BASIC NETWORK CAPACITANCE (CB01 = 0) IS 900 FEET.
NOTE 2: CEECO C-101A OR HYBRID IN FIGURE 9.
NOTE 3: HEATH CO. TYPE DC-1 DECADE CAPACITOR. OR PRECISE TYPE 478
NOTE 4: STRAP TERMINALS 2, 3 and 4 FOR 19H88. LEAVE TERMINALS 2, 3 AND 4 UNSTRAPPED FOR 22H88. BASIC NETWORK CAPACITANCE (CB02 = 0) IS 900 FEET.
AC-VTVM
HP 400D, H, L OR 403B, A
OFFICE A
MEASUREMENT PROCEDURE
OFFICE B

DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Connect the test equipment and cable pair under test as shown above. Be sure to short terminals 2, 3, and 4 in PBN's Nos. 1 and 2 for 19 gauge and leave unstrapped for 22 gauge.

2. Set CB01 in PBN No. 1 to .033 μf. Set CB02 to build out PBN No. 2 to same value as physical length of cable end section. (Remember! 900 feet of this is already in the basic net of the PBN.) Set C_2 to build-out cable end section to 3000' total.

3. Throw DPDT switch to "CALIBRATE" position. Set oscillator frequency to 2000 cps and vary output level until AC VTVM reads 0 dbm (Zero dbm); this completes calibration. Throw DPDT switch to "MEASURE" position. Do not change oscillator output level control.

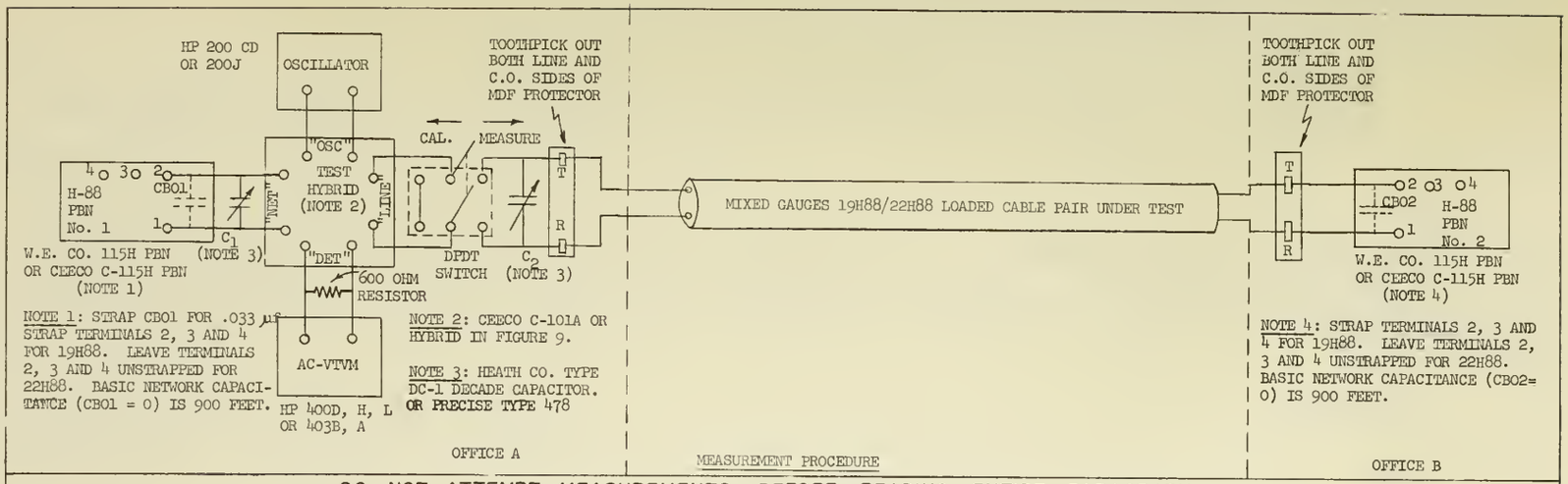
4. Vary oscillator frequency vernier, slowly, between 200 to 3400 cps and note the frequencies which give consecutive maximum (peak) and minimum (valley) readings on the AC VTVM. Read each peak and valley frequency and the minus dbm reading on the AC VTVM corresponding to each and enter the results on the "Data Sheet - Structural Return Loss Measurements."

5. Increase value of C_2 from that in step (2) and repeat step (4). Note whether SRL becomes better or worse particularly between 2500 to 3000 cps. (SRL becomes better as readings in AC VTVM get more negative.) If SRL gets better this means that end section is electrically less than 3000 feet (though by length alone it is 3000 feet). Vary C_2 until the value is found that gives the best SRL (especially between 2500 to 3000 cps).

6. Increase C_2 in step (5). If SRL gets worse, this means that the cable end section is longer than 3000 feet electrically. Return C_2 to its original value in step (2) (to give 3000 feet end-section total). Increase C_1 until the best possible SRL is obtained (especially between 2500 to 3000 cps). Record the results in the "Data Sheet - Structural Return Loss Measurements."

7. If by increasing C_1 or C_2 SRL gets worse, this means that the end section as built out in step (2) to 3000 feet is not only 3000 feet in length but also 3000 feet electrically, which is the important thing. If this is the case, continue with the measurement as per item (4) and record the data in the "Data Sheet - Structural Return Loss Measurements."

FIGURE 13. SINGLE FREQUENCY STRUCTURAL RETURN LOSS MEASUREMENT OF ONE UNIFORM GAUGE ONLY FOR ENTIRE CIRCUIT LENGTH (19H88 or 22H88)



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Connect the test equipment and cable pair as shown above. Set gauge of PBN No. 1 for most predominant gauge adjacent to hybrid and PBN No. 2 for most predominant gauge adjacent to it.

2. Set CB01 in PBN No. 1 to .033 µf. Set CB02 to build out PBN No. 2 to same value as physical length of cable end section. (Remember! 900 feet is already in the basic net of the PBN.) Set C_2 to build-out cable end section to 3000' total.

3. Throw DPDT switch to "CALIBRATE" position. Set oscillator frequency to 2000 cps and vary output level control until AC-VTVM reads 0 dbm (zero dbm); this completes calibration. Do not change oscillator output level control. Throw DPDT switch to "MEASURE" position.

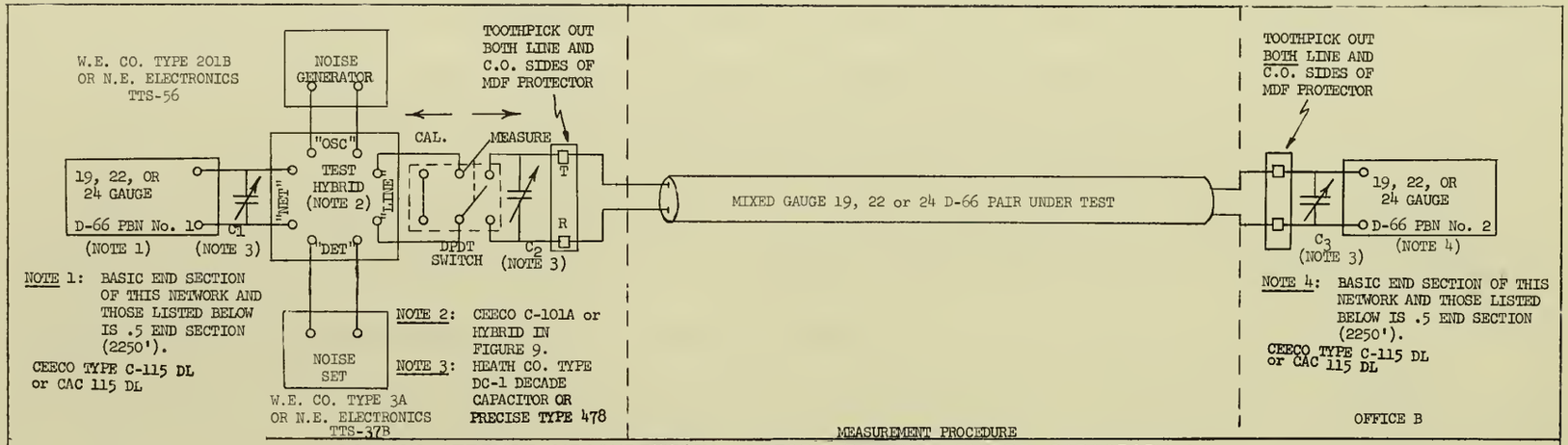
4. Vary oscillator frequency vernier, slowly, between 200 to 3400 cps and note the frequencies which give consecutive maximum (peak) and minimum (valley) readings on the AC -VTVM. Read each peak and valley frequency and the minus dbm reading on the AC -VTVM corresponding to each. Change gauge of PBN No. 1 (if it is set for 19 gauge in step (1), change it to 22 gauge) and note if this improves the SRL. If it does, leave set for new gauge setting; if not, change back to original gauge. Change gauge of PBN No. 2 from that in step (1) and note if this improves SRL. If it does, leave set for new gauge setting; if not, change back to original gauge. (VARYING GAUGE OF PBN NOS. 1 AND 2 ALTERNATELY WILL BE NECESSARY, DEPENDING ON ACTUAL CABLE LAYOUT, TO OBTAIN BEST SRL.) Record best SRL in the "Data Sheet-Structural Return Loss Measurements."

5. Increase value of C_2 from that in step (2) and repeat step (4). Note whether SRL becomes better or worse particularly between 2500 to 3000 cps (SRL becomes better as readings in AC -VTVM get more negative.) If SRL gets better this means that end section is electrically less than 3000 feet (though by length alone it is 3000 feet). Vary C_2 until the value is found that gives the best SRL (especially between 2500 to 3000 cps).

6. If by increasing C_2 in step (5), SRL gets worse, this means that the cable end section is longer than 3000 feet electrically. Return C_2 to its original value in step (2) (to give 3000 feet end-section total). Increase C_1 until the best possible SRL is obtained (especially between 2500 to 3000 cps). Record the results in the "Data Sheet-Structural Return Loss Measurements."

7. If by increasing C_1 or C_2 SRL gets worse, this means that the end section as built out in step (2) to 3000 feet is not only 3000 feet in length but also 3000 feet electrically, which is the important thing. If this is the case, continue with the measurement as per item (4) and record the data in the "Data Sheet-Structural Return Loss Measurements."

FIGURE 14. SINGLE FREQUENCY STRUCTURAL RETURN LOSS MEASUREMENT OF H-88 LOADED CABLES WITH MIXED 22 and 19 GAUGES



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Calibrate the 3A NMS by itself and the 201B by itself before proceeding with the measurement according to Calibration instructions.

2. Connect the test equipment and cable pair under test as shown above. Be sure to strap or set PBN "gauge terminals" for same gauge as gauge of cable being measured. Set C_2 to build-out cable end section to 3000' total.

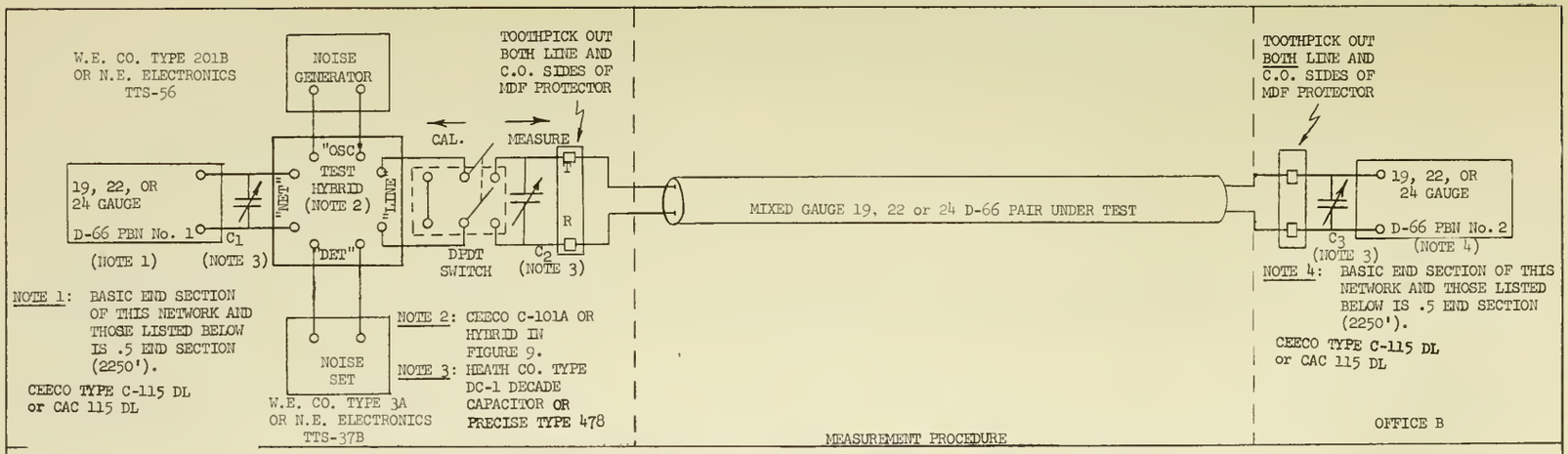
3. Throw DPDT switch to "CALIBRATE" position. Set "OUTPUT ATTEN." pad of 201B noise generator to the 8 db position and note the reading on the 3A NMS. 3A should read 89 dbrn-C. (Function switch of 3A must be in "NM 600" position and "C-Message Network" must be plugged in.) If 3A reads slightly higher or lower than this adjust "OUTPUT ATTEN." pad of 201B until the 89 dbrn-C is obtained on the 3A NMS. This completes calibration. Throw DPDT switch to "MEASURE" position. Do not change 201B output level control.

4. Read dbrn-C reading in 3A NMS. Vary C_2 and/or C_1 until lowest (best) reading is obtained in 3A NMS. This is the best reading and it is the one which should be recorded. Also, vary the C_3 at the far end. See if reading on 3A gets lower (better). If it does record this reading. If not, record the best reading (varying C_3 will normally have no effect on the 3A NMS if the circuit has a loss of 5 db or greater).

5. The echo structural return loss (ESRL) in db is the difference between: [ESRL = 89 - dbrn-C reading, step (5)] in db.

6. Record the data in DATA SHEET - ECHO STRUCTURAL RETURN LOSS (ESRL) FOR D-66 LOADING.

FIGURE 15. ECHO STRUCTURAL RETURN LOSS MEASUREMENT (ESRL) OF ONE UNIFORM GAUGE ONLY FOR ENTIRE CIRCUIT LENGTH (19-D-66 ONLY OR 22-D-66 ONLY OR 24-D-66 ONLY)



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Calibrate the 3A NMS by itself and the 201B by itself before proceeding with the measurement according to Calibration instructions.

2. Connect the test equipment and cable pair under test as shown above. Be sure to strap or set PBN "gauge terminals" for same gauge as the predominant cable gauge being measured. Set C_2 to build-out cable end section to 2250' total.

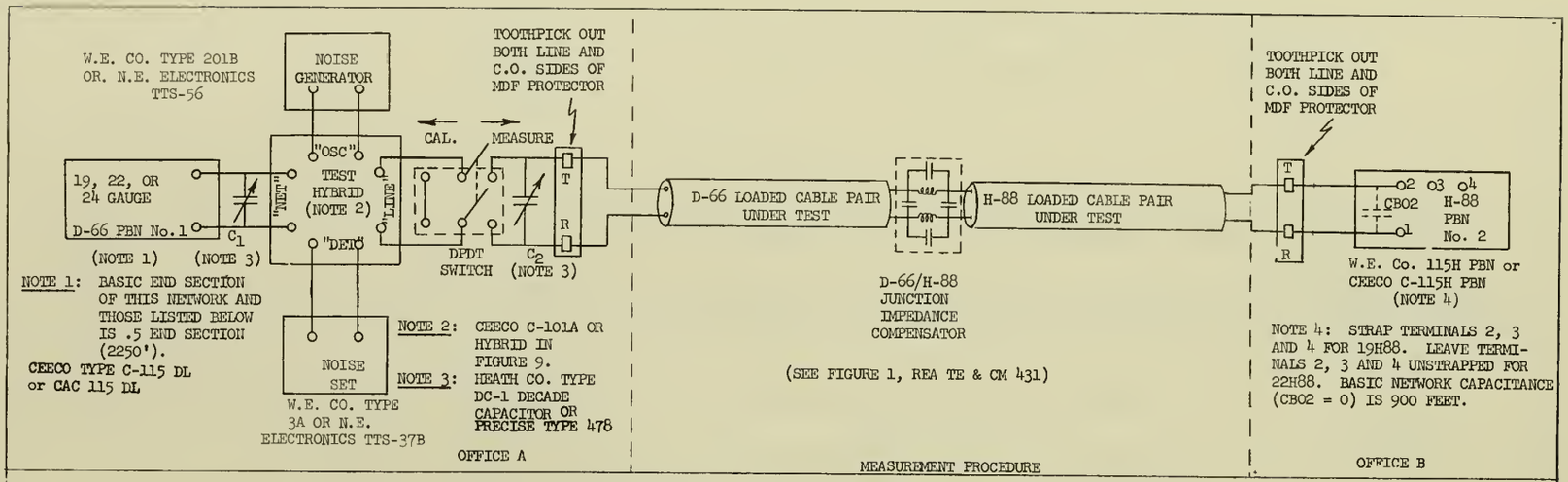
3. Throw DPDT switch to "CALIBRATE" position. Set "OUTPUT ATTEN." pad of 201B noise generator to the 8 db position and note the reading on the 3A NMS. The 3A should read 89 dbrn-C. (Function switch of 3A NMS must be on "NM 600" position and "C-Message Network" must be plugged in.) If 3A reads slightly higher or lower than this, adjust "OUTPUT ATTEN." pad of 201B until the 89 dbrn-C is obtained on the 3A. This completes calibration. Throw DPDT switch to "MEASURE" position. Do not change 201B output level pad.

4. Read dbrn-C reading in 3A NMS. Vary C_2 or C_1 until lowest (best) reading is obtained on 3A. Next, vary the gauge of PBN No. 1 and PBN No. 2 until the reading on 3A becomes the lowest possible. (This procedure involves varying C_1, C_2, gauge of PBN No. 1 and No. 2 until the combination is found which produces the lowest reading on the 3A NMS.) The lowest reading on the 3A is the reading to record.

5. The echo structural return loss (ESRL) in db is: [ESRL = 89 - dbrn-C reading, step (5)] in db.

6. Record the data in DATA SHEET - ECHO STRUCTURAL RETURN LOSS (ESRL) FOR D-66 LOADING.

FIGURE 16. ECHO STRUCTURAL RETURN LOSS (ESRL) MEASUREMENT OF D-66 LOADED CABLES WITH MIXED 19, 22 and 24 GAUGES



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

Measuring at the D-66 end

1. If gauge is uniform, that is all 19 gauge or all 22 gauge for both the D-66 and H-88 cables, use the measuring procedure in Figure 15.

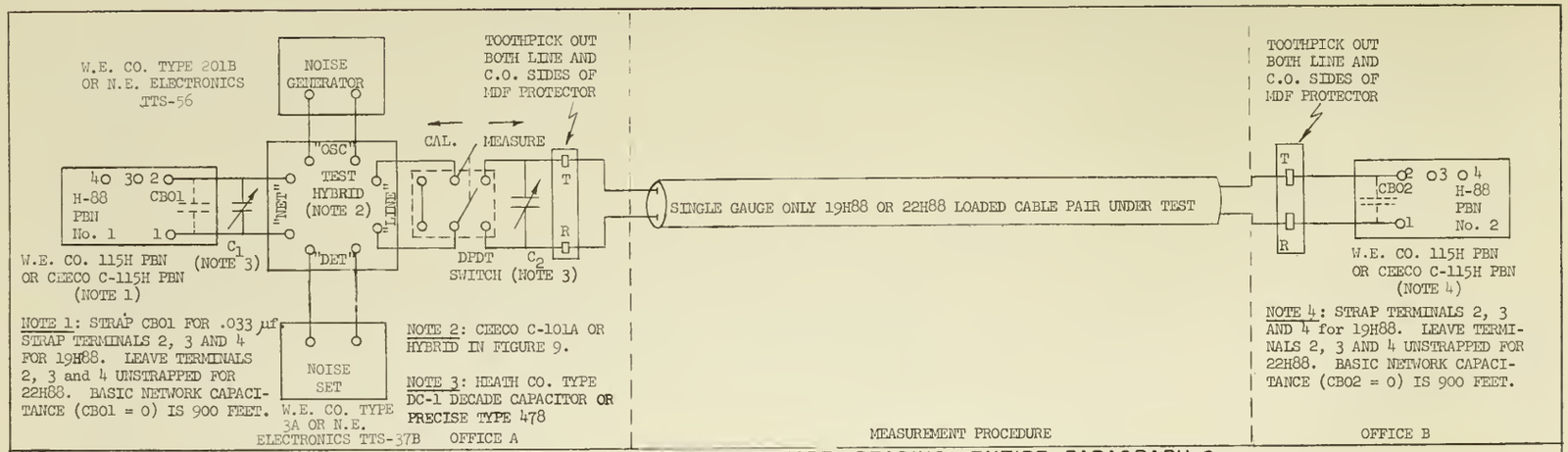
2. If gauges are mixed, use measurement procedure of Figure 16.

Measuring at the H-88 end

3. If the gauge is uniform, that is all 19 gauge or all 22 gauge for both the D-66 and H-88 cables, use the measuring procedure in Figure 18.

4. If gauges are mixed, use measurement procedure of Figure 19.

FIGURE 17. ECHO STRUCTURAL RETURN LOSS MEASUREMENT OF D-66/H-88 LOADED CABLE USING THE D-66/H-88 JUNCTION IMPEDANCE COMPENSATOR



NOTE 1: STRAP CB01 FOR .033 μf STRAP TERMINALS 2, 3 AND 4 FOR 19H88. LEAVE TERMINALS 2, 3 and 4 UNSTRAPPED FOR 22H88. BASIC NETWORK CAPACITANCE (CB01 = 0) IS 900 FEET.

NOTE 2: CEECO C-101A OR HYBRID IN FIGURE 9.

NOTE 3: HEATH CO. TYPE DC-1 DECADE CAPACITOR OR PRECISE TYPE 478

NOTE 4: STRAP TERMINALS 2, 3 AND 4 for 19H88. LEAVE TERMINALS 2, 3 AND 4 UNSTRAPPED FOR 22H88. BASIC NETWORK CAPACITANCE (CB02 = 0) IS 900 FEET.

DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Calibrate the 3A NMS by itself and the 201B by itself before proceeding with the measurement according to calibration instructions.

2. Connect the test equipment and cable pair under test as shown above. Make certain that terminals 4, 5 and 6 in PBN Nos. 1 and 2 are strapped (shorted) for 19-gauge and left unstrapped for 22 gauge.

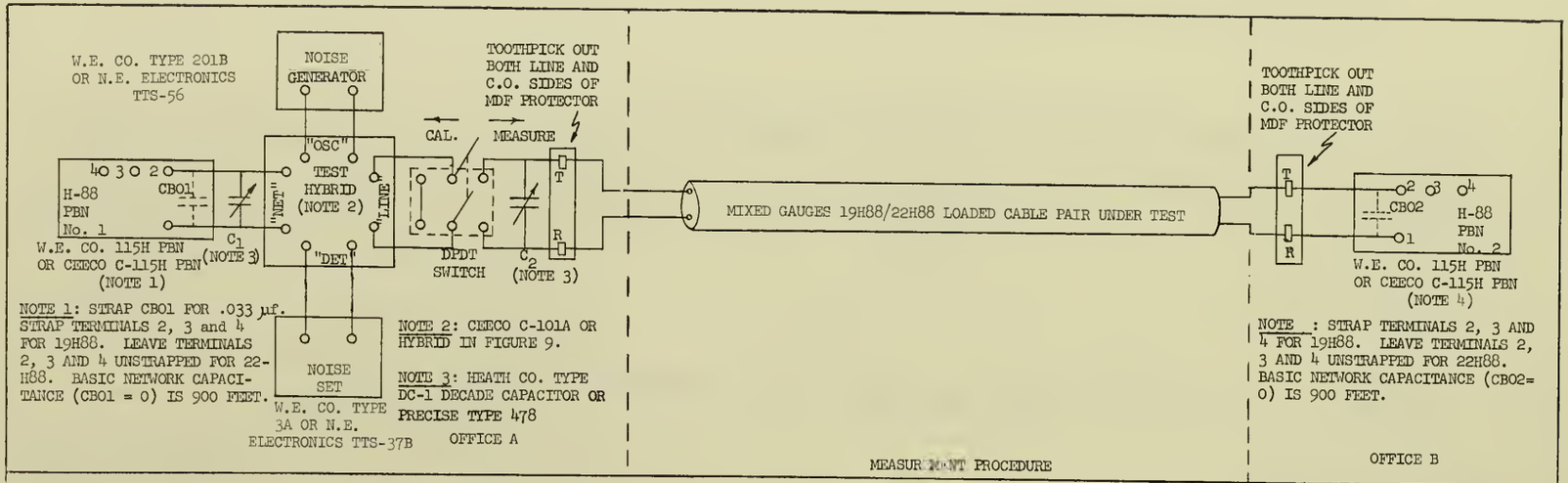
3. Set CB01 in PBN No. 1 to .033 μf. Set CB02 to build out PBN No. 2 to same value as physical length of cable end section. (Remember! 900 feet of this is already in the basis net of the PBN.) Set C_2 to build-out cable end section to 3000' total.

4. Throw DPDT switch to "CALIBRATE" position. Set "OUTPUT ATTEN." pad of 201B noise generator to the 8 db position and note the reading on the 3A NMS. 3A should read 89 dbrn-C. (Function switch of 3A must be in "NM 600" position and "C-Message Network" must be plugged in.) If 3A reads slightly higher or lower than this adjust "OUTPUT ATTEN." pad of 201B until the 89 dbrn-C is obtained on the 3A NMS. This completes calibration. Throw DPDT switch to "MEASURE" position. Do not change 201B output level control.

5. Read dbrn-C reading in 3A NMS. Vary C_2 and/or C_1 until lowest (best) reading is obtained in 3A NMS. This is the best reading and it is the one which should be recorded. Also vary the C_3 at the far end. See if reading on 3A gets lower (better). If it does record this reading. If not, record the best reading (varying C_3 will normally have no effect on the 3A NMS if the circuit has a loss of 5 db or greater).

6. The echo structural return loss (ESRL) in db is the difference between: [ESRL = 89 - dbrn-C reading, step (5)] in db.

FIGURE 18. ECHO STRUCTURAL RETURN LOSS MEASUREMENT (ESRL) OF ONE UNIFORM GAUGE ONLY FOR ENTIRE CIRCUIT LENGTH (19-H-88 ONLY OR 22-H-88 ONLY)



DO NOT ATTEMPT MEASUREMENTS BEFORE READING ENTIRE PARAGRAPH 8

1. Calibrate the 3A NMS by itself and the 201B by itself before proceeding with measurement according to calibration instructions.

2. Connect the test equipment and cable pair as shown above.

3. Throw DPDT switch to "CALIBRATE" position. Set "OUTPUT ATTEN." pad of 201B noise generator to the 8 db position and note the reading on the 3A NMS. The 3A should read 89 dbrn-C. (Function switch of 3A NMS must be on "NM 600" position and "C-Message Network" must be plugged in.) If 3A reads slightly higher or lower than this, adjust "OUTPUT ATTEN." pad of 201B until the 89 dbrn-C is obtained on the 3A. This completes calibration. Throw DPDT switch to "MEASURE" position. Do not change 201B output level pad.

4. Set CB01 in PBN No. 1 to .033 µf. Set CB02 to build out PBN No. 2 to same value as physical length of cable end section. (Remember! 900 feet of this is already in the basic net of the PBN.) Set C_2 to build-out cable end section to 3000' total.

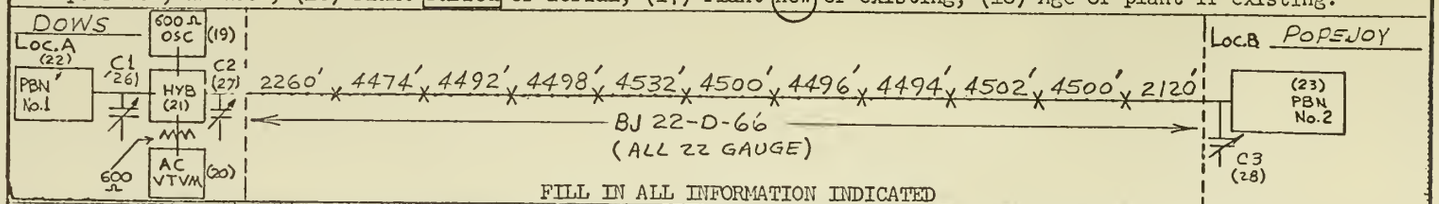
5. Read dbrn-C reading in 3A NMS. Vary C_2 and/or C_1 until lowest (best) reading is obtained on 3A. Next, vary the gauge of PBN No. 1 and PBN No. 2 until the reading on 3A becomes the lowest possible. (This procedure involves varying C_1, C_2, gauge of PBN No. 1 and No. 2 until the combination is found which produces the lowest reading on the 3A NMS.) The lowest reading on the 3A is the reading to record.

6. The echo structural return loss (ESRL) in db is: [ESRL = 89 - dbrn-C reading, step (5)] in db.

FIGURE 19. ECHO STRUCTURAL RETURN LOSS (ESRL) MEASUREMENT OF H-88 LOADED CABLES WITH MIXED 19 AND 22 GAUGES

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. IOWA 501-D (2) TRK.GROUP DOWS TO ALDEN (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN DOWS TO POPEJOY (5) TRUNK NO. LOC. A ___, LOC. B ___ (6) PAIR NO. LOC. A 6, LOC.B 6
(7) TEMP. AIR ____°F (IF Aerial), GD. ___°F (If Buried) (8) TESTERS PGL, HPP (9) DATE MEASMS. 7/14/58
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

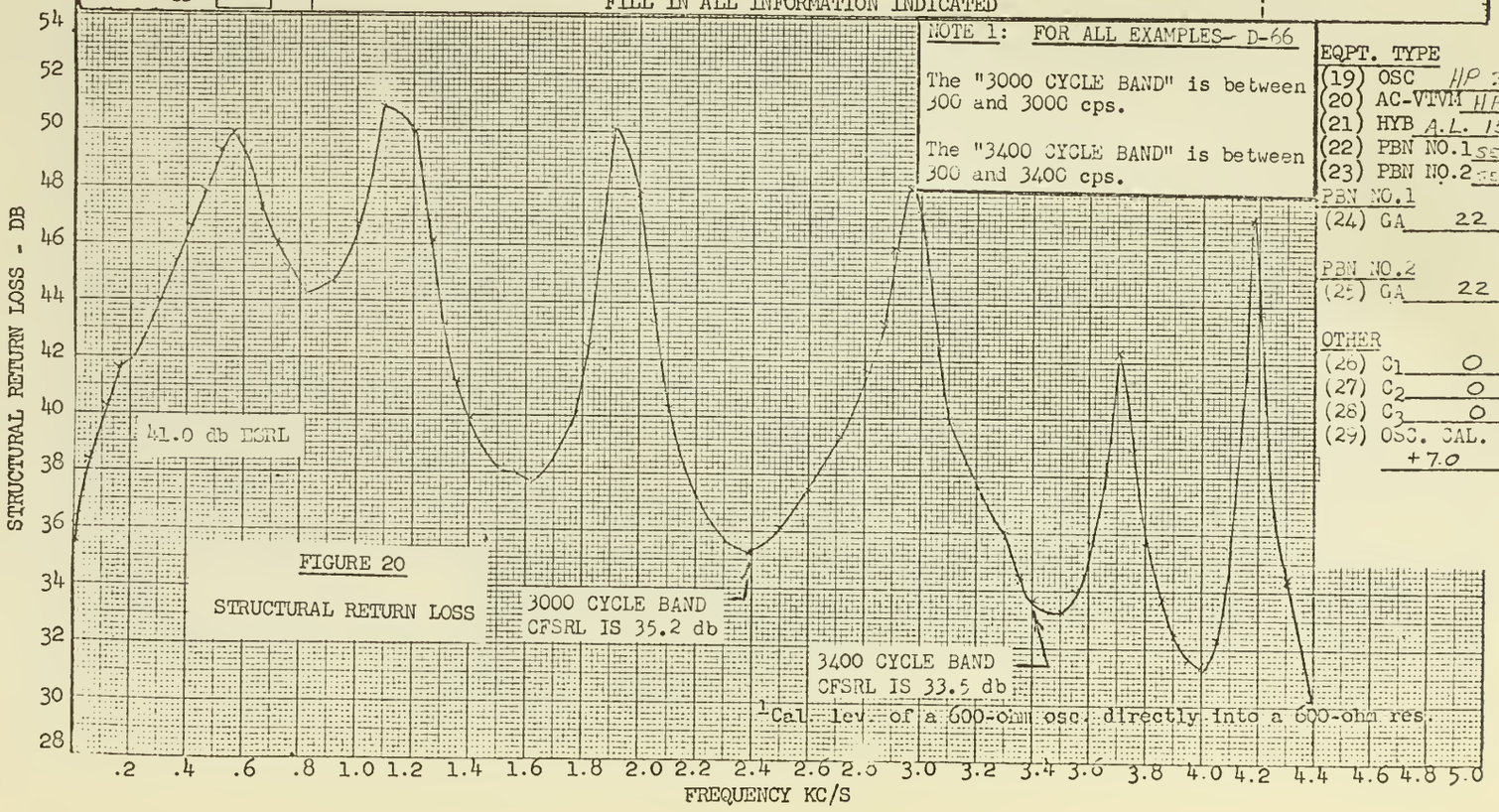


FIGURE 20

STRUCTURAL RETURN LOSS

NOTE 1: FOR ALL EXAMPLES- D-66

The "3000 CYCLE BAND" is between 300 and 3000 cps.

The "3400 CYCLE BAND" is between 300 and 3400 cps.

EQPT. TYPE
(19) OSC HP 200J
(20) AC-VTVM HP 400L
(21) HYB A.L. 15189
(22) PBN NO.1 SEE FIG 2
(23) PBN NO.2 SEE FIG 5

PBN NO.1
(24) GA 22

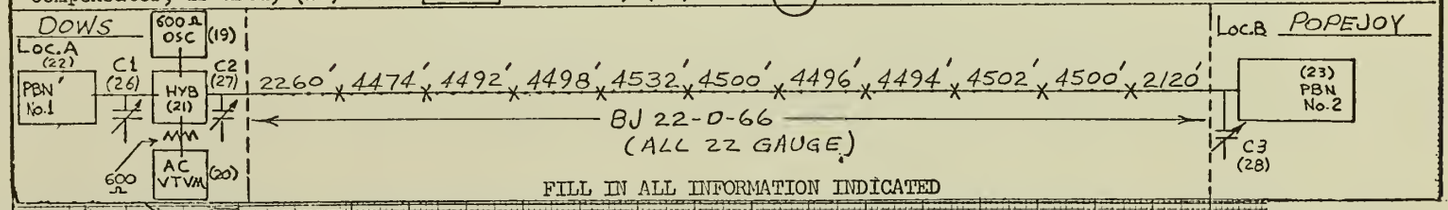
PBN NO.2
(25) GA 22

OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV.[1] +7.0 DBM

[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. IOWA 501-D (2) TRK.GROUP DOWS TO ALDEN (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN DOWS TO POPEJOY (5) TRUNK NO. LOC. A ___, LOC. B ___ (6) PAIR NO. LOC. A 2, LOC.B ___
(7) TEMP. AIR ___°F (IF Aerial), GD. ___°F (If Buried) (8) TESTERS [illegible] (9) DATE MEASMS. 7/14/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

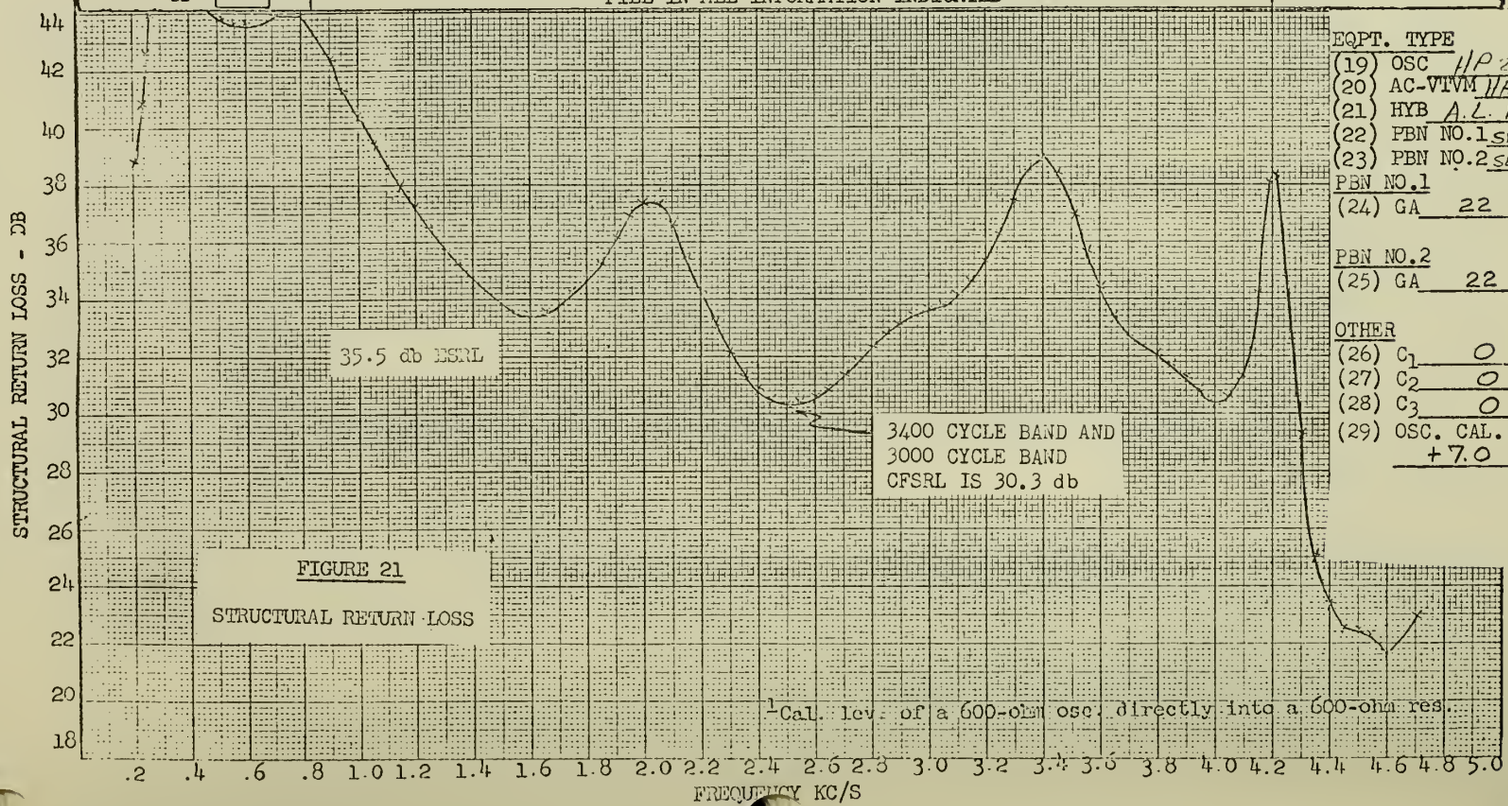


FIGURE 21

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC HP 200 J
(20) AC-VTVM HP 400 L
(21) HYB A.L. 15189
(22) PBN NO.1 SEE FIG 3
(23) PBN NO.2 SEE FIG 3

PBN NO.1
(24) GA 22

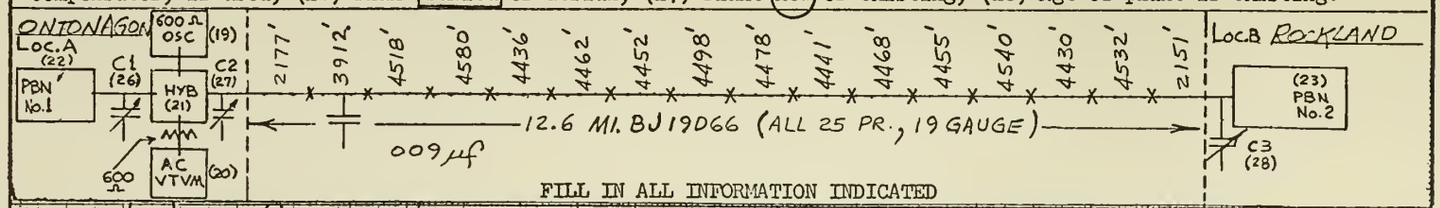
PBN NO.2
(25) GA 22

OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV.[1] +7.0 DBM

[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) RFA PROJ. DESIGN. MICHIGAN 529 A (2) TRK.GROUP ONTONAGON TO IRON MTN (3) (TOLL), EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN ONTONAGON TO ROCKLAND (5) TRUNK NO. LOC. A SP, LOC. B SP (6) PAIR NO. LOC. A 21, LOC. B 21
(7) TEMP. AIR ____ °F (IF Aerial), GD. ____ °F (If Buried) (8) TESTERS PGL, JHP (9) DATE MEASMS. 8/19/65
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

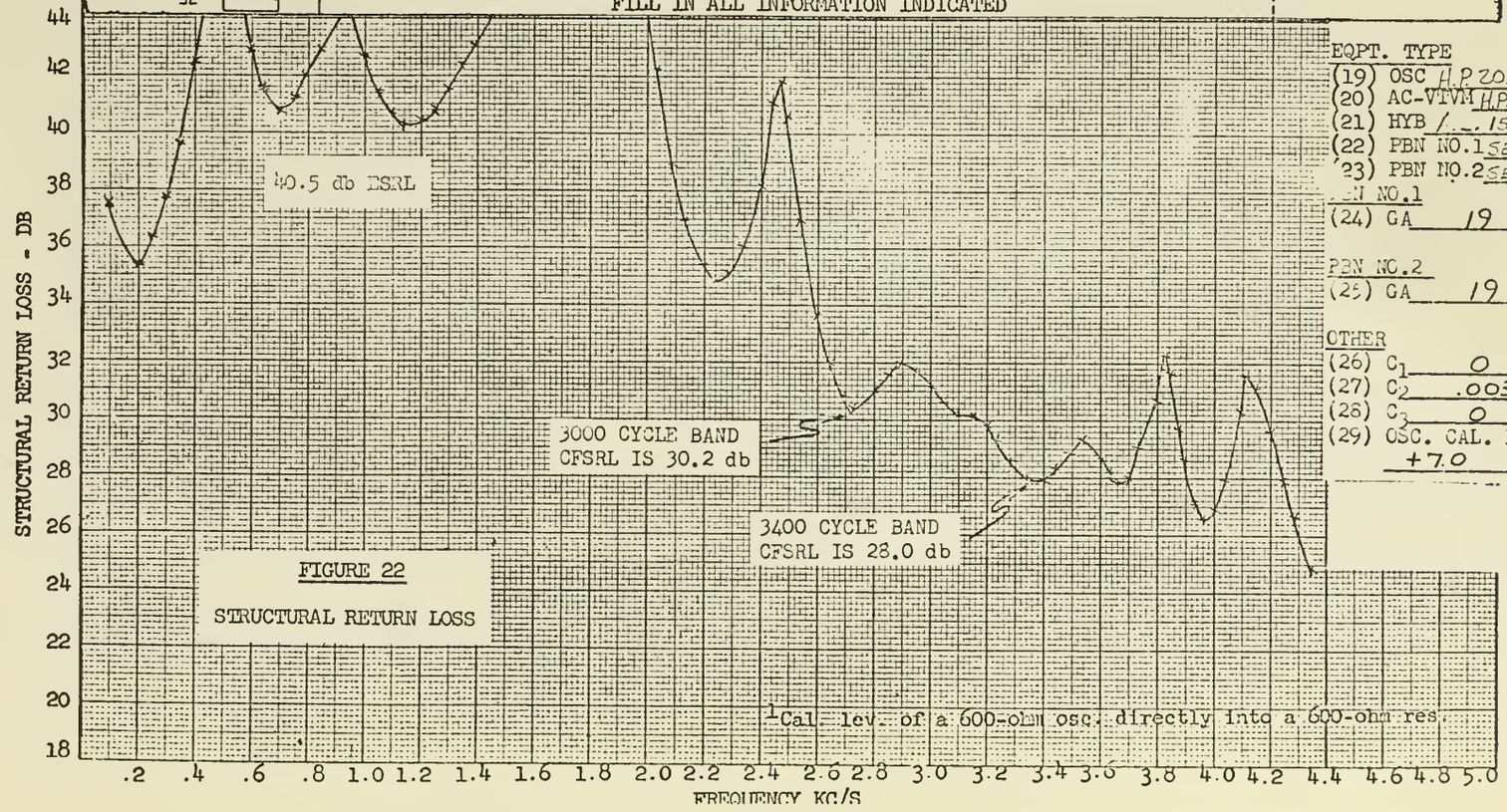


FIGURE 22

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC H.P. 200J
(20) AC-VTVM H.P. 400L
(21) HYB /_ . 15199
(22) PBN NO.1 SEE FIG 5
(23) PBN NO.2 SEE FIG 5

PBN NO.1
(24) GA 19

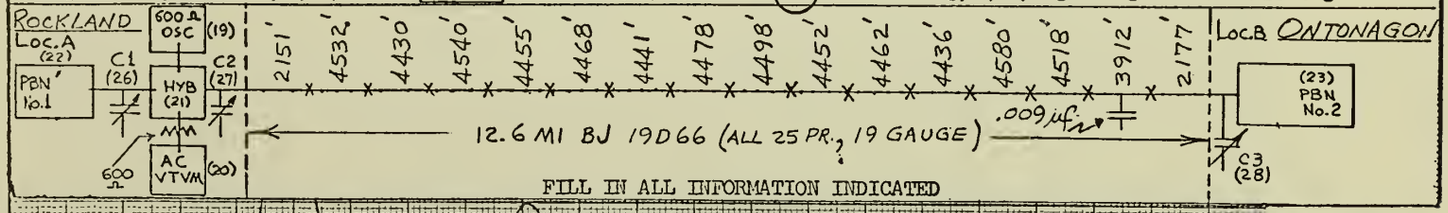
PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF
(27) C_2 .003 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV.[1] +7.0 DBM

[1] Cal lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. MICHIGAN 529 A (2) TRK.GROUP ONTONAGON TO IRON MTN (3) (TOLL), EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN ROCKLAND TO ONTONAGON (5) TRUNK NO. LOC. A SP., LOC. B SP. (6) PAIR NO. LOC. A 21, LOC.B 21
(7) TEMP. AIR ____°F (IF Aerial), GD. ____°F (If Buried) (8) TESTERS BGL, HLR (9) DATE MEASMS. 8/19/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

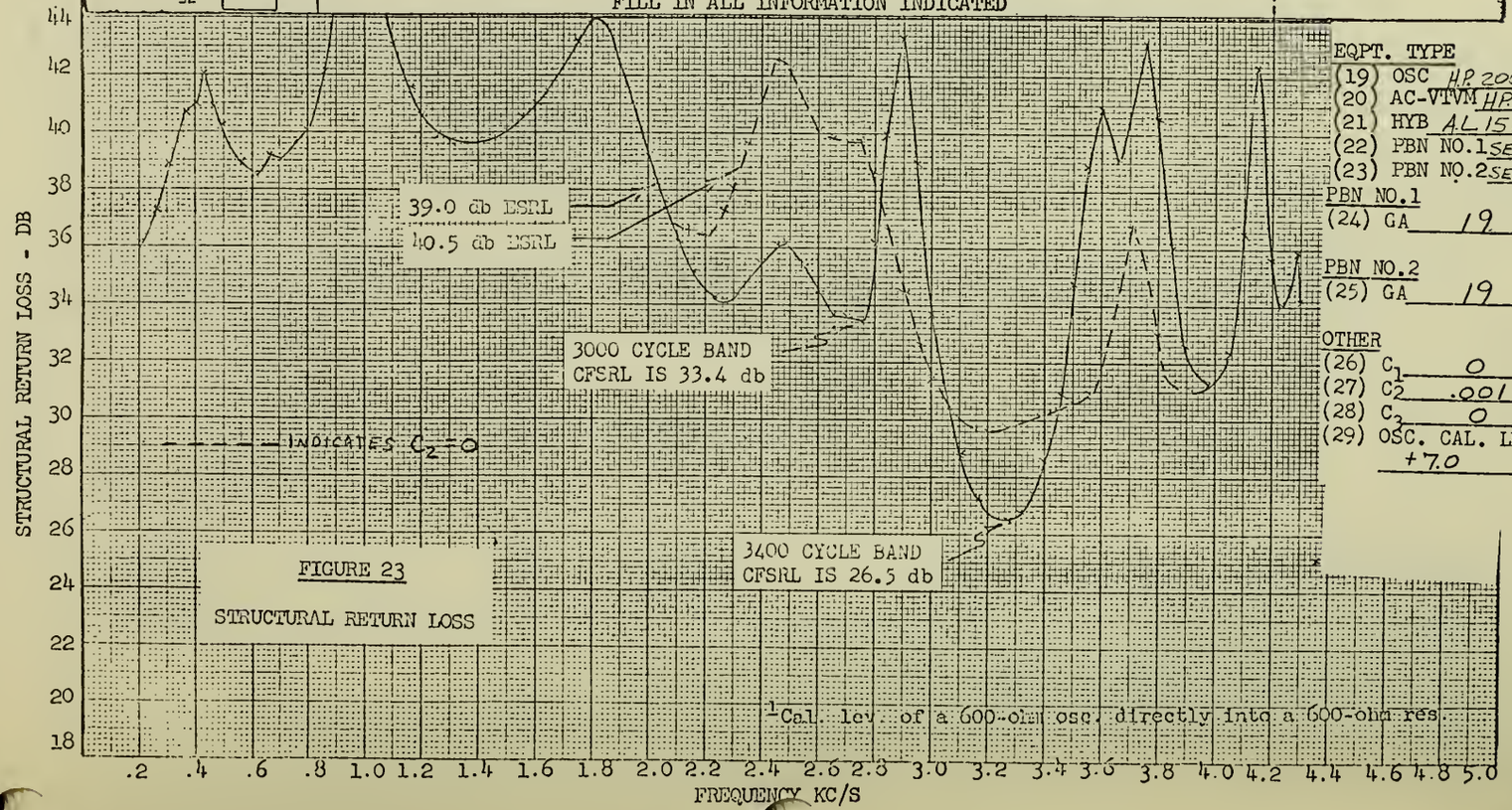


FIGURE 23

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC HP 200 J
(20) AC-VTVM HP 400L
(21) HYB AL 15189
(22) PBN NO.1 SEE 71G3
(23) PBN NO.2 SEE 71G3

PBN NO.1
(24) GA 19

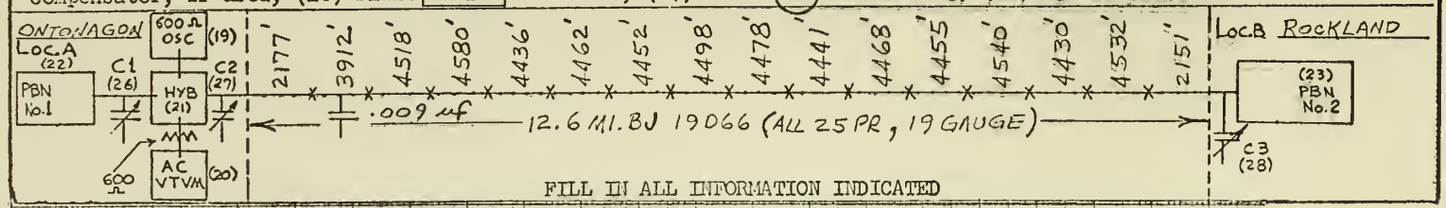
PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF
(27) C_2 .001 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. 1
+7.0 DBM

[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. MICHIGAN 529 A (2) TRK.GROUP ONTONAGON TO WOODMERE (3) (TOLL), FAS, SPEC. (Circle One)
(4) MEASURING BETWEEN ONTONAGON TO ROCKLAND (5) TRUNK NO. LOC. A SP, LOC. B SP (6) PAIR NO. LOC. A 8, LOC.B 8
(7) TEMP. AIR ____°F (IF Aerial), GD. ____°F (If Buried) (8) TESTERS JGL, JHE (9) DATE MEASMS. 8/19/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

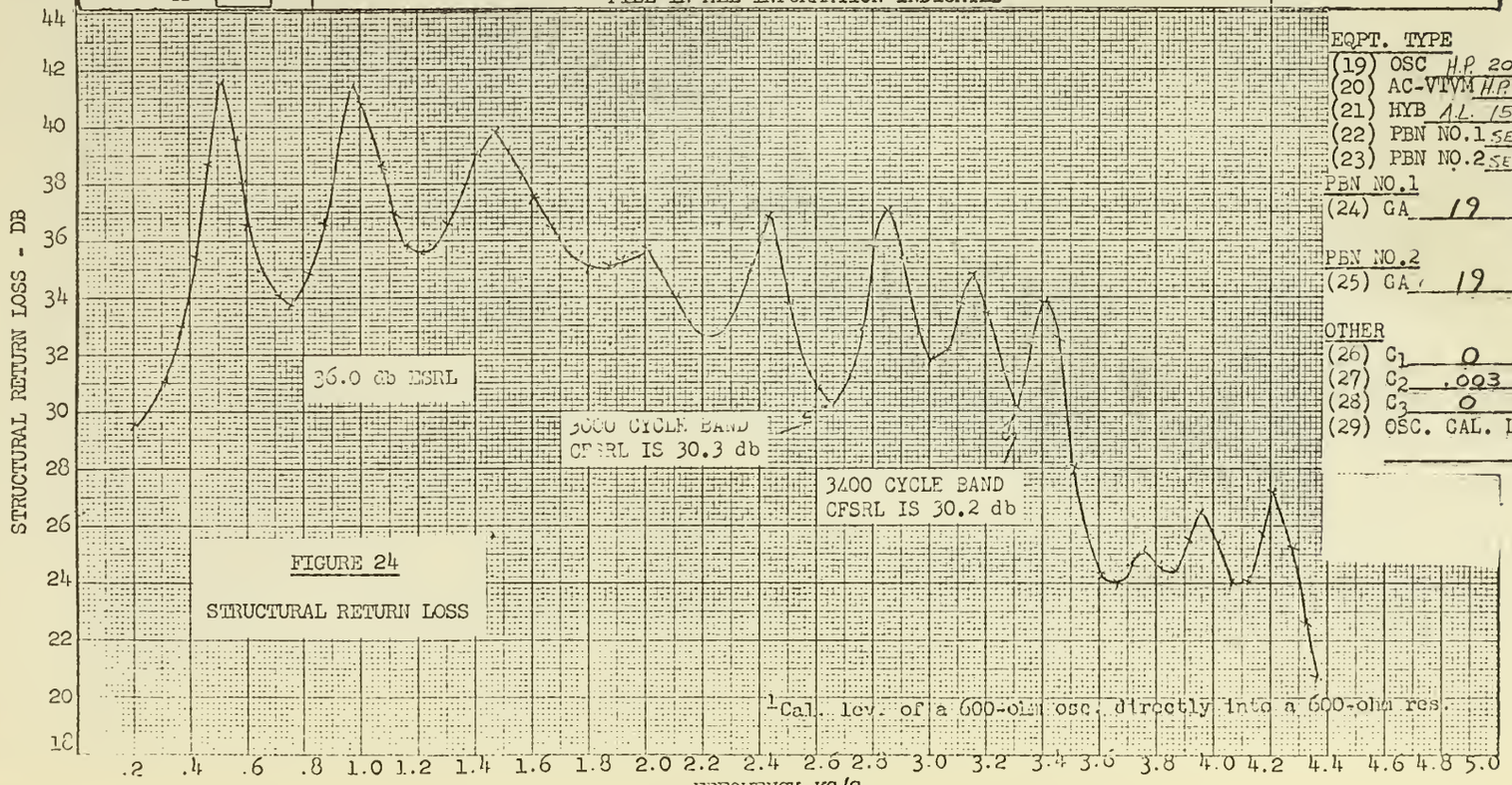


FIGURE 24

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC H.P. 200 J
(20) AC-VTVM H.P. 400 L
(21) HYB AL. 15189
(22) PBN NO.1 SEE 71G3
(23) PBN NO.2 SEE 71G3

PBN NO.1
(24) GA 19

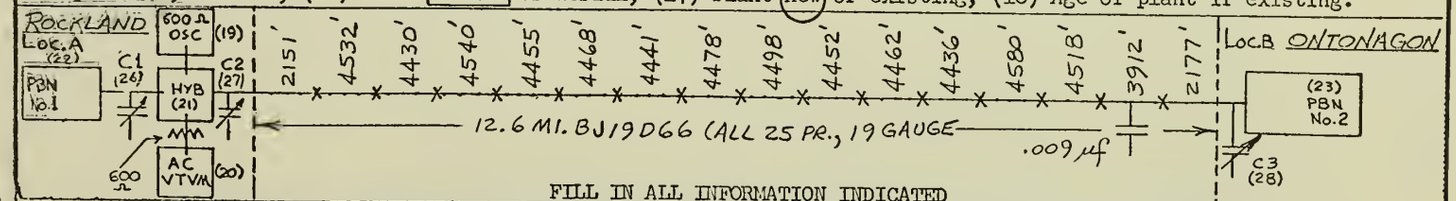
PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF.
(27) C_2 .003 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. ____ DBM

[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. MICHIGAN 529 A (2) TRK.GROUP ONTONAGON TO IRON MTN (3) (TOLL), EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN ROCKLAND TO ONTONAGON (5) TRUNK NO. LOC. A SP, LOC. B SP (6) PAIR NO. LOC. A 8, LOC. B 8
(7) TEMP. AIR ____ °F (If Aerial), GD. 65 °F (If Buried) (8) TESTERS PGL, JHP (9) DATE MEASMS. 8/19/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

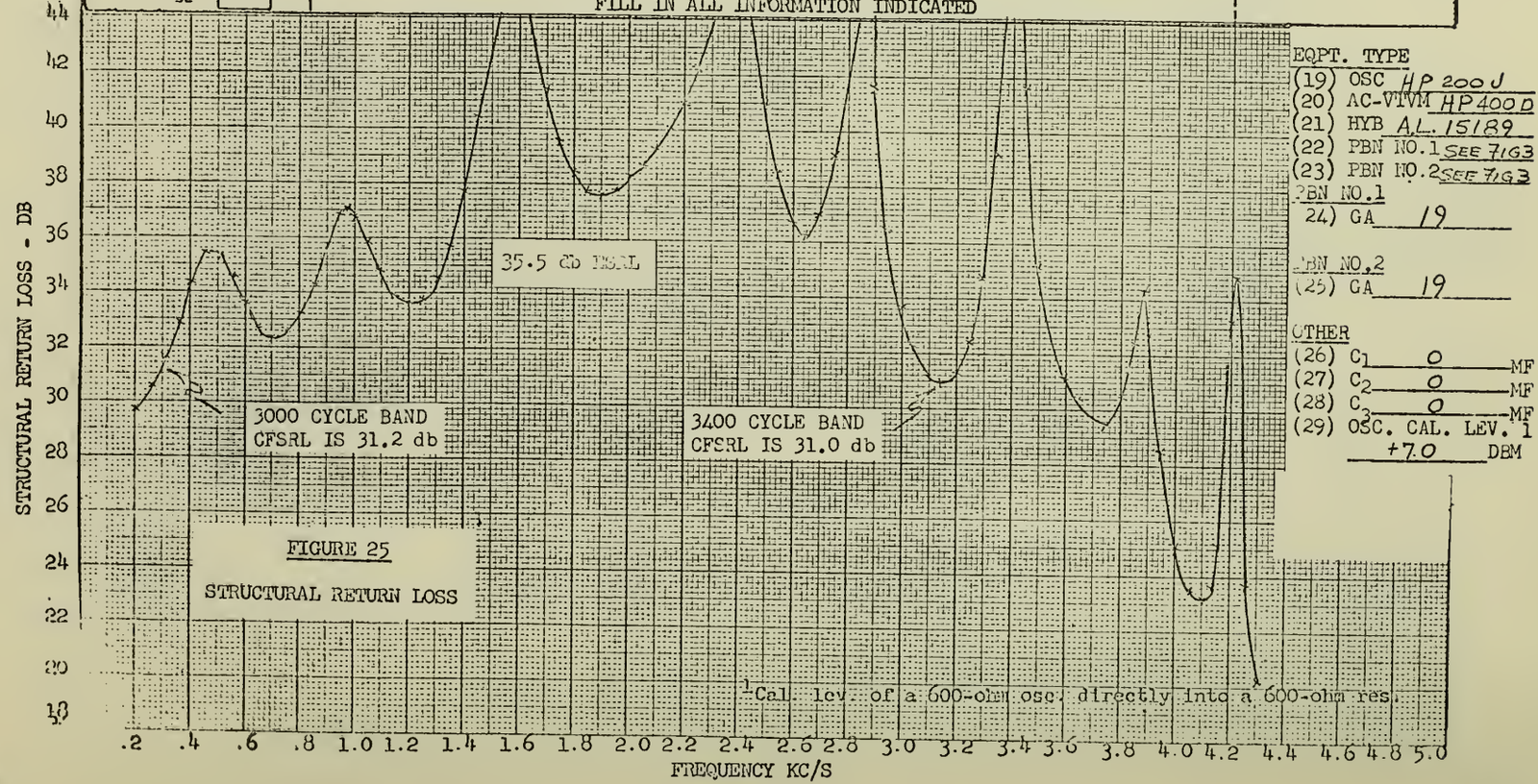


FIGURE 25

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC HP 200 J
(20) AC-VTVM HP 400 D
(21) HYB A.L. 15189
(22) PBN NO.1 SEE FIG 3
(23) PBN NO.2 SEE FIG 3

PBN NO.1
(24) GA 19

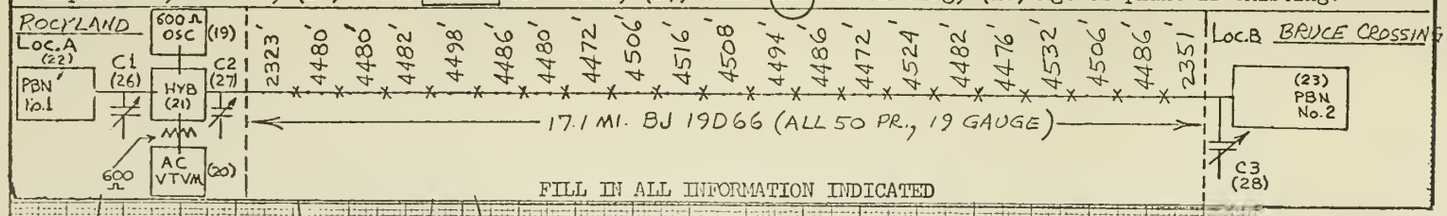
PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV.[1] +7.0 DBM

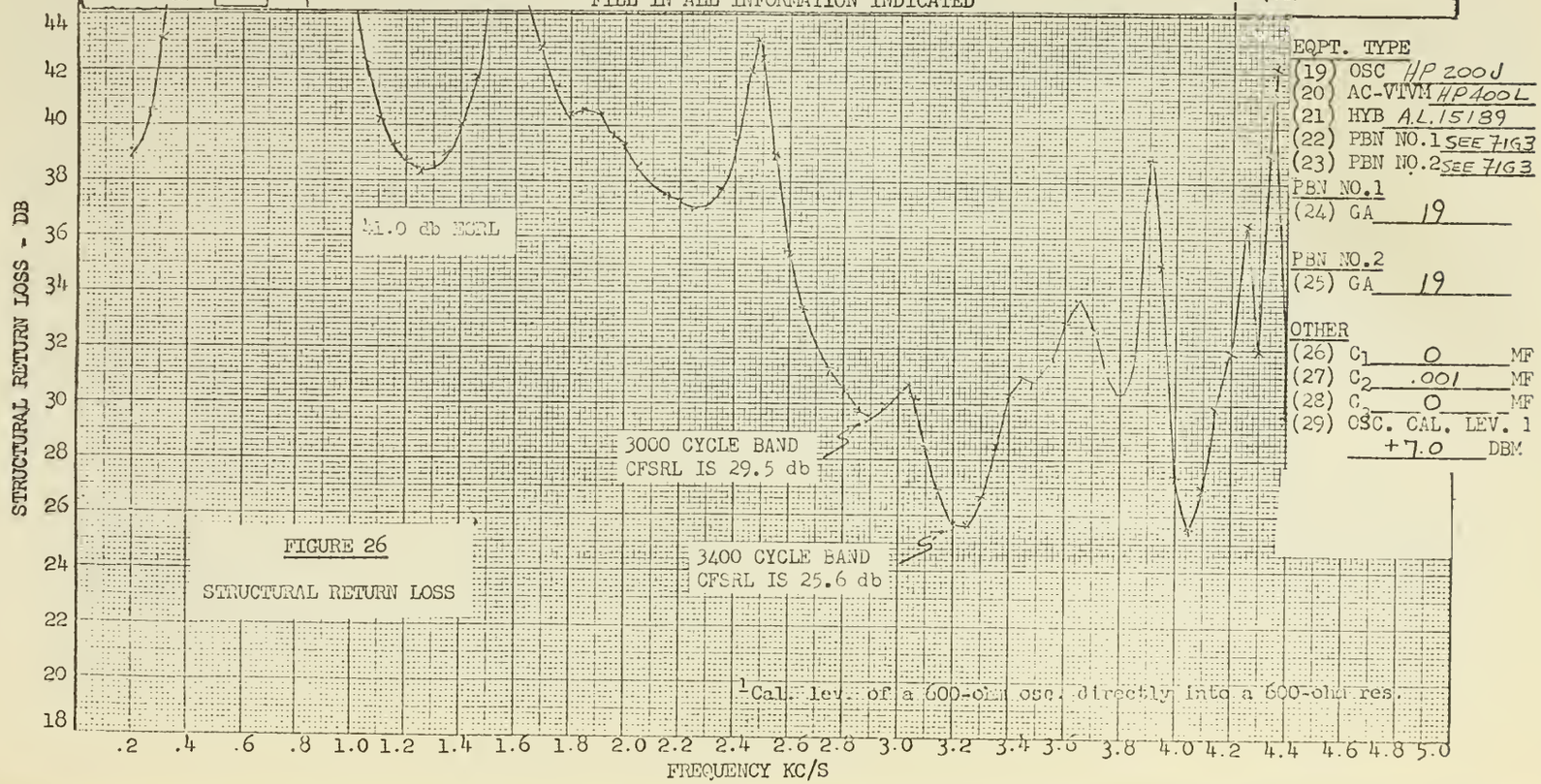
[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. MICHIGAN 529 A (2) TRK.GROUP ROCKLAND TO BRUCE CROSS (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN ROCKLAND TO BRUCE CROSS. (5) TRUNK NO. LOC. A SP, LOC. B SP (6) PAIR NO. LOC. A 11, LOC.B 11
(7) TEMP. AIR _____ °F (IF Aerial), GD. ___ °F (If Buried) (8) TESTERS D.G.L. J.R.S. (9) DATE MEASMS. 8/20/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant buried or aerial, (17) Plant new or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED



EQPT. TYPE
(19) OSC HP 200J
(20) AC-VTVM HP400L
(21) HYB A.L.15189
(22) PBN NO.1 SEE FIG3
(23) PBN NO.2 SEE FIG3

PBN NO.1
(24) GA 19

PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF
(27) C_2 .001 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. 1
+7.0 DBM

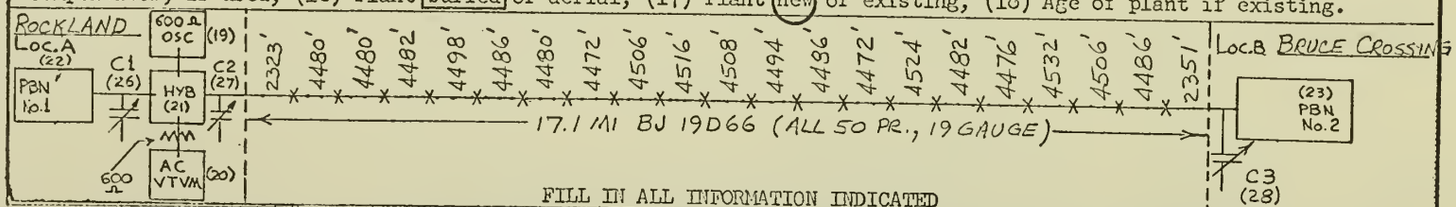
FIGURE 26

STRUCTURAL RETURN LOSS

[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. MICHIGAN 529-A (2) TRK.GROUP ONTONAGON TO IRON RIVER (3) TOLL, EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN ROCKLAND TO BRUCE CROSS. (5) TRUNK NO. LOC. A SP, LOC. B SP (6) PAIR NO. LOC. A 20, LOC. B 20
(7) TEMP. AIR ____°F (IF Aerial), GD. ____°F (If Buried) (8) TESTERS [illegible] (9) DATE MEASMS. 8/20/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant buried or aerial, (17) Plant new or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

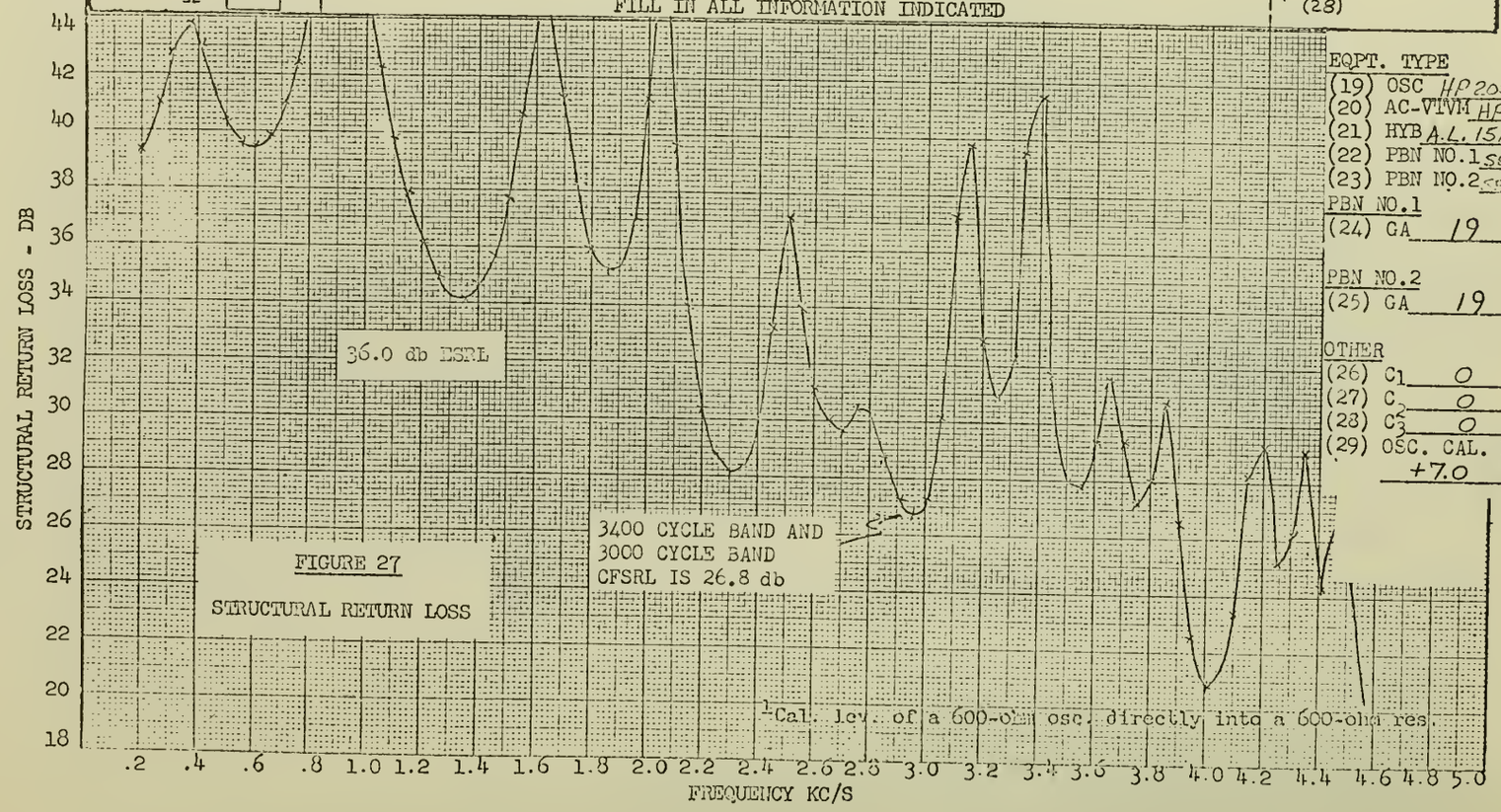


FIGURE 27

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC HP200J
(20) AC-VTVM HP400L
(21) HYB A.L. 15189
(22) PBN NO.1 SEE 71G3
(23) PBN NO.2 SEE 71G3

PBN NO.1
(24) GA 19

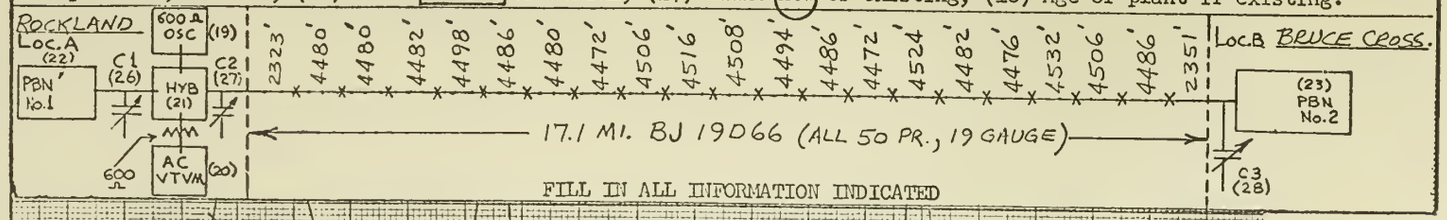
PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. 1 +7.0 DBM

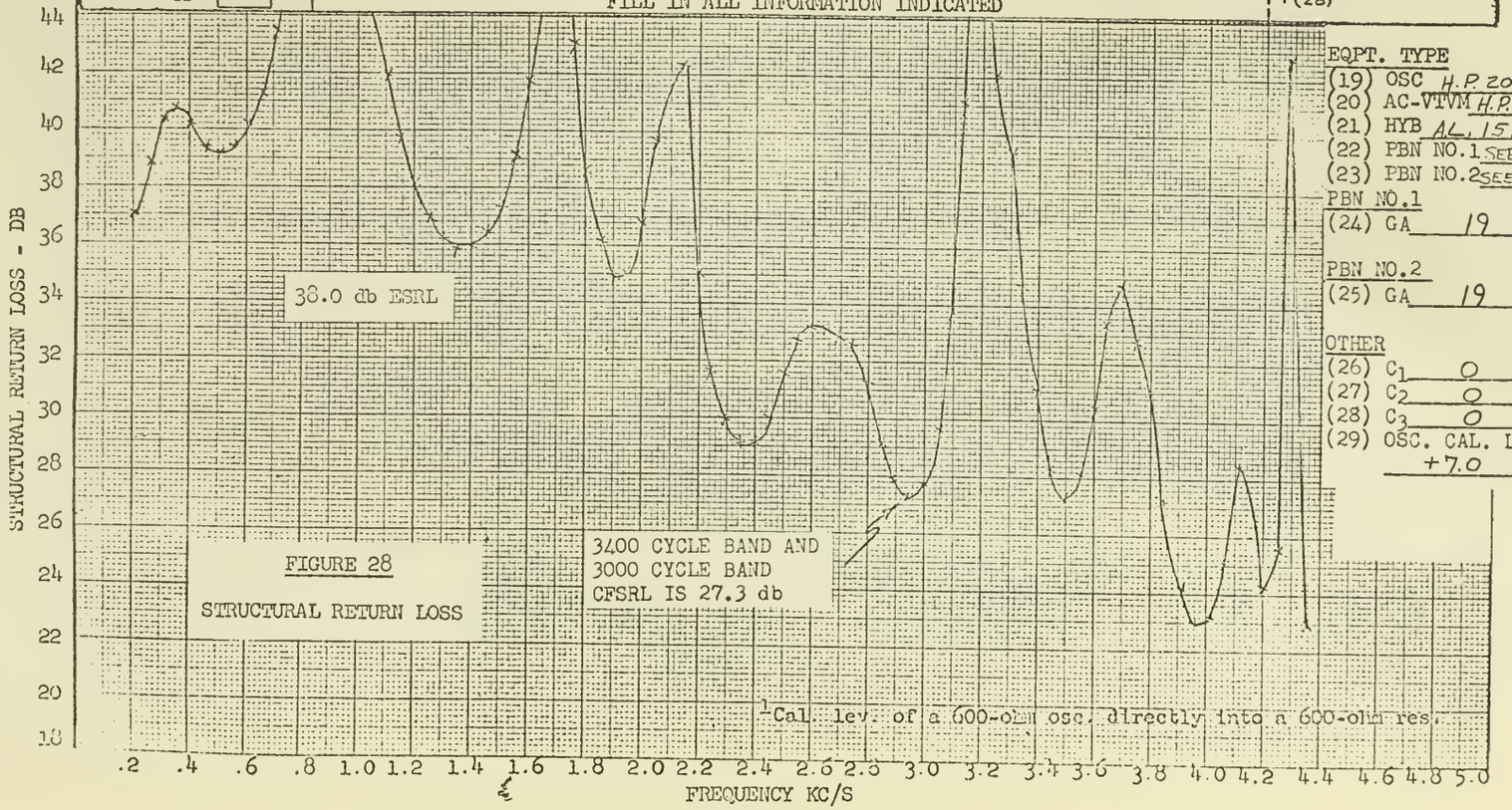
[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. MICHIGAN 529 A (2) TRK.GROUP ROCKLAND TO BRUCE CROSS (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN ROCKLAND TO BRUCE CROSS. (5) TRUNK NO. LOC. A SP, LOC. B SP (6) PAIR NO. LOC. A 21, LOC. B 21
(7) TEMP. AIR ____ °F (IF Aerial), GD. ____ °F (If Buried) (8) TESTERS BGL, JLP (9) DATE MEASMS. 8/20/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED



EQPT. TYPE
(19) OSC H.P. 200 J
(20) AC-VTVM H.P. 400 L
(21) HYB AL. 15189
(22) PBN NO.1 SEE FIG 3
(23) PBN NO.2 SEE FIG 3

PBN NO.1
(24) GA 19

PBN NO.2
(25) GA 19

OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. [1] +7.0 DBM

FIGURE 28

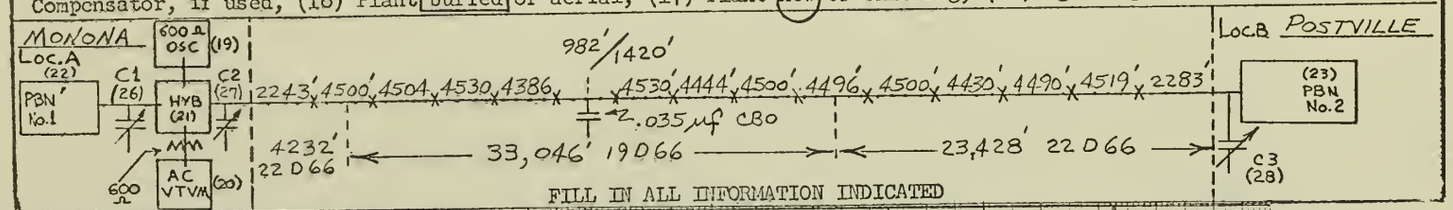
STRUCTURAL RETURN LOSS

[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

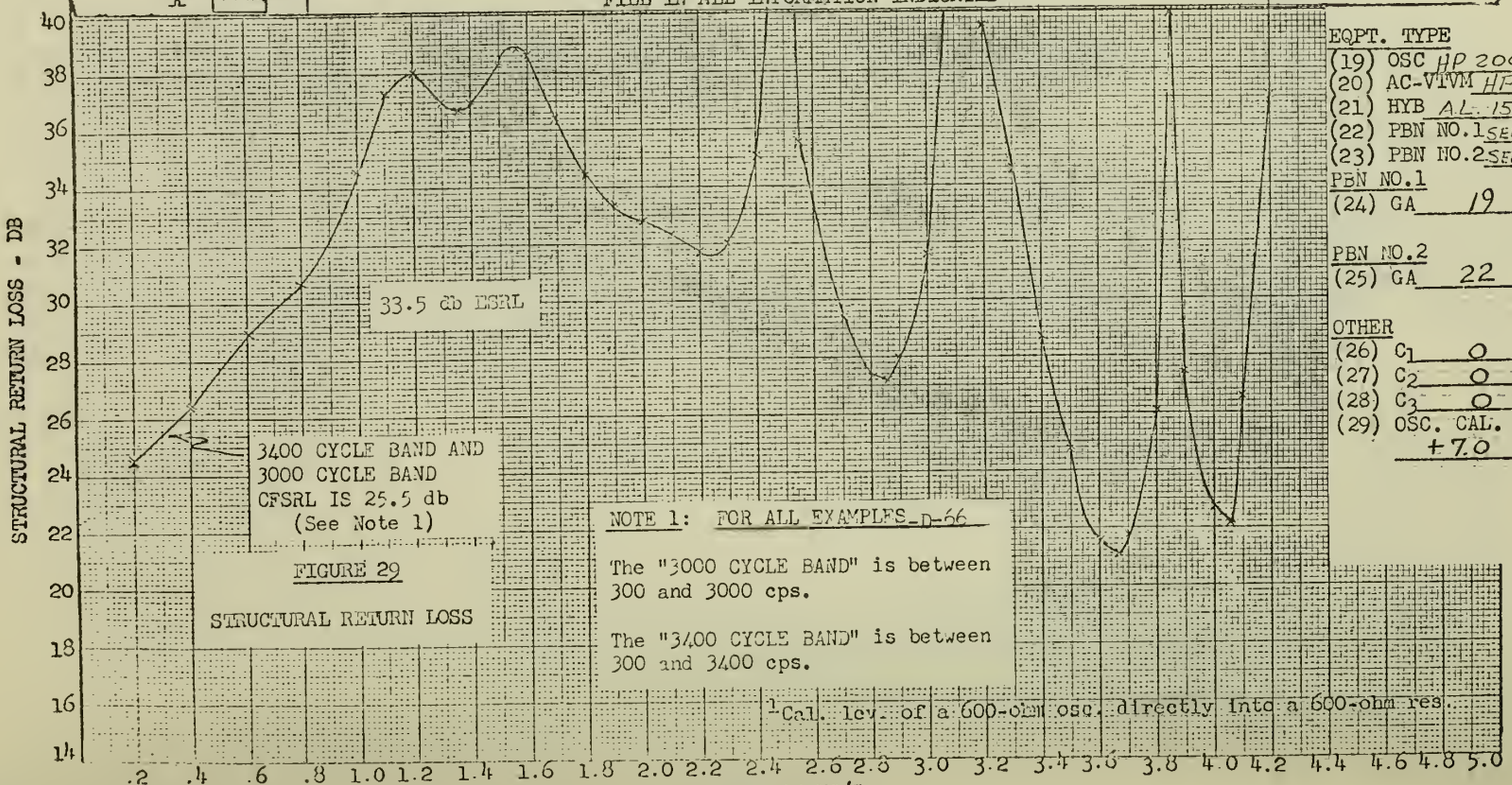
FIGURE 21 - Drainage Unit

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. IOWA 583-A (2) TRK.GROUP MONONA TO POSTVILLE (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN MONONA TO POSTVILLE (5) TRUNK NO. LOC. A 1, LOC. B 1 (6) PAIR NO. LOC. A 251, LOC. B 1251
(7) TEMP. AIR ____ °F (IF Aerial), GD. ____ °F (If Buried) (8) TESTERS PGL, HHP (9) DATE MEASMS. 7/10/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-built length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED



EQPT. TYPE
(19) OSC HP 200 J
(20) AC-VTVM HP400L
(21) HYB AL. 15139
(22) PBN NO.1 SEE 71G3
(23) PBN NO.2 SEE 71G3

PBN NO.1
(24) GA 19

PBN NO.2
(25) GA 22

OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. 1
+7.0 DBM

FIGURE 29

STRUCTURAL RETURN LOSS

NOTE 1: FOR ALL EXAMPLES D-66

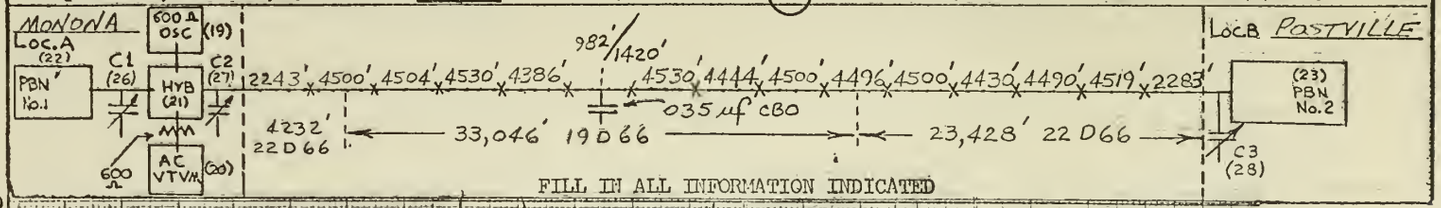
The "3000 CYCLE BAND" is between 300 and 3000 cps.

The "3400 CYCLE BAND" is between 300 and 3400 cps.

[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. IOWA 583-A (2) TRK.GROUP MONONA TO POSTVILLE (3) TOLL, (EAS) SPEC. (Circle One)
(4) MEASURING BETWEEN MONONA TO POSTVILLE (5) TRUNK NO. LOC. A 8, LOC. B (6) PAIR NO. LOC. A [illegible] LOC.B 1253
(7) TEMP. AIR ____ °F (IF Aerial), GD. ____ °F (If Buried) (8) TESTERS [illegible] (9) DATE MEASMS. 7/10/63
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

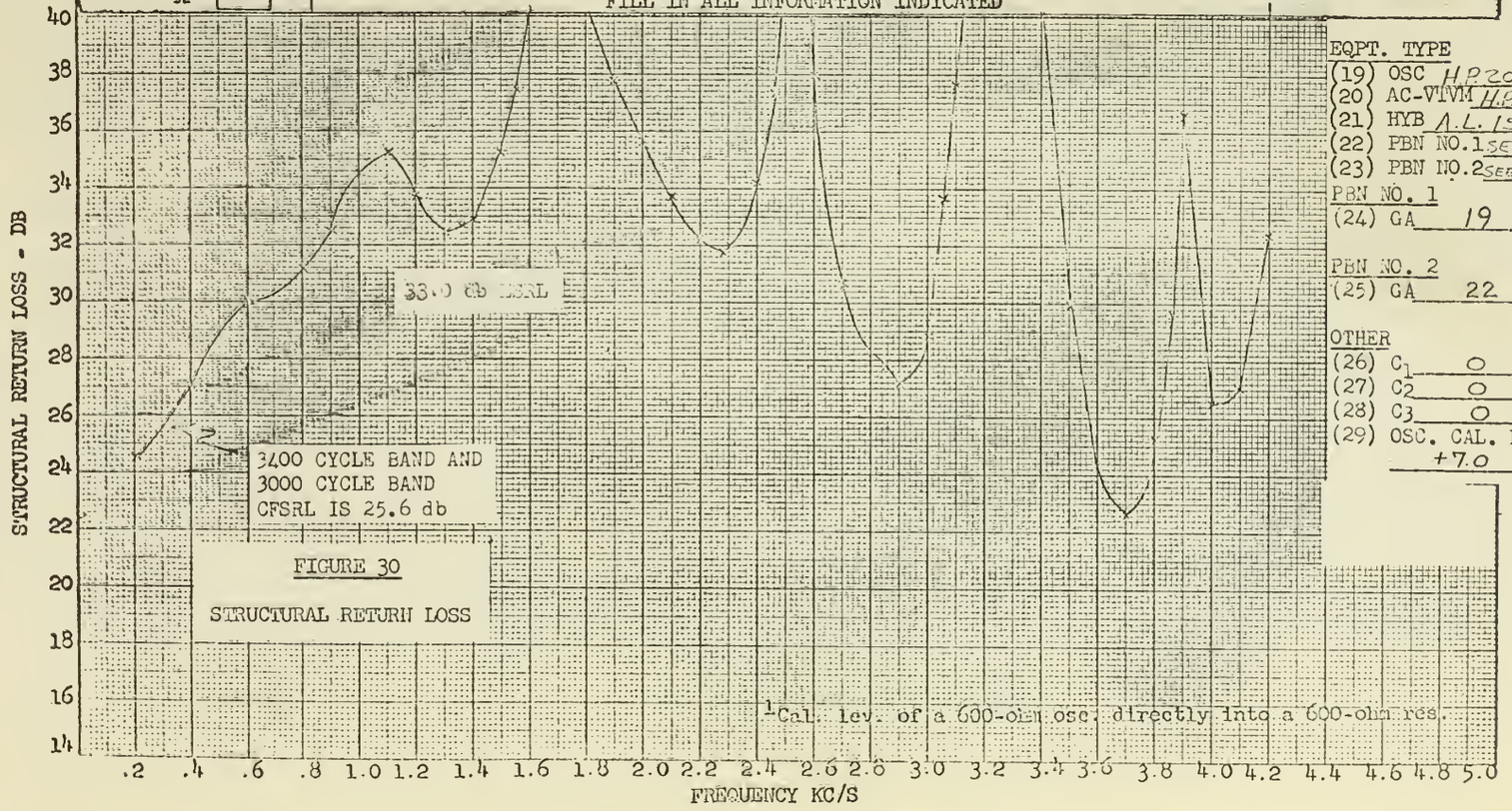


FIGURE 30

STRUCTURAL RETURN LOSS

EQPT. TYPE
(19) OSC HP200J
(20) AC-VTVM HP400L
(21) HYB A.L. 15189
(22) PBN NO.1 SEE FIG 3
(23) PBN NO.2 SEE FIG 3

PBN NO. 1
(24) GA 19

PBN NO. 2
(25) GA 22

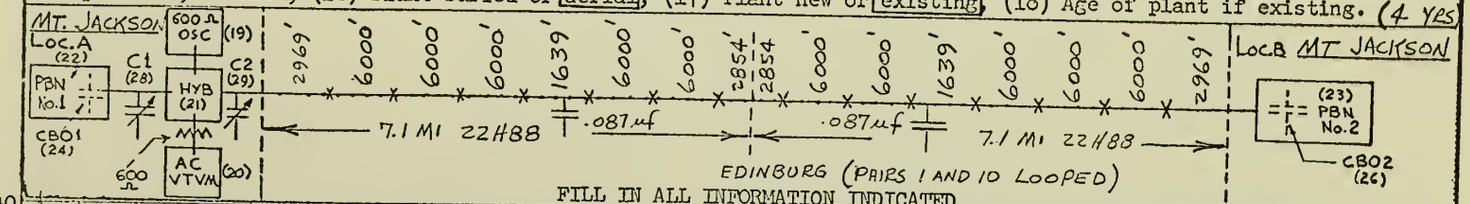
OTHER
(26) C_1 0 MF
(27) C_2 0 MF
(28) C_3 0 MF
(29) OSC. CAL. LEV. 1 +7.0 DBM

[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

FIGURE 21- Drainage Unit

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR H-88 LOADING

(1) REA PROJ. DESIGN. VA. 517 EDINBURG (2) TRK.GROUP MT JACKSON TO EDINBURG (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN MT. JACKSON TO MT JACKSON (5) TRUNK NO. LOC. A 1,1 LOC. B 1,10 (6) PAIR NO. LOC. A ___ LOC.B ___
(7) TEMP. AIR ___ °F (IF Aerial), GD. ___ °F (If Buried) (8) TESTERS JMA, GMC (9) DATE MEASMS. 11/16/62
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant buried or [aerial], (17) Plant new or [existing], (18) Age of plant if existing. (4 YRS)



FILL IN ALL INFORMATION INDICATED

EQPT. TYPE
(19) OSC H.P.200J
(20) AC-VTVM HP400L
(21) HYB 120 P
(22) PBN NO.1 REA-H-88
(23) PBN NO.2 REA-H-88
PBN NO. 1
(24) CBO1 0 MF
(25) GA 22
PBN NO. 2
(26) CBO2 0 MF
(27) GA 22
OTHER
(28) C1 0 MF
(29) C2 0 MF
(30) OSC.CAL.LEV.[1] +7.0 DBM

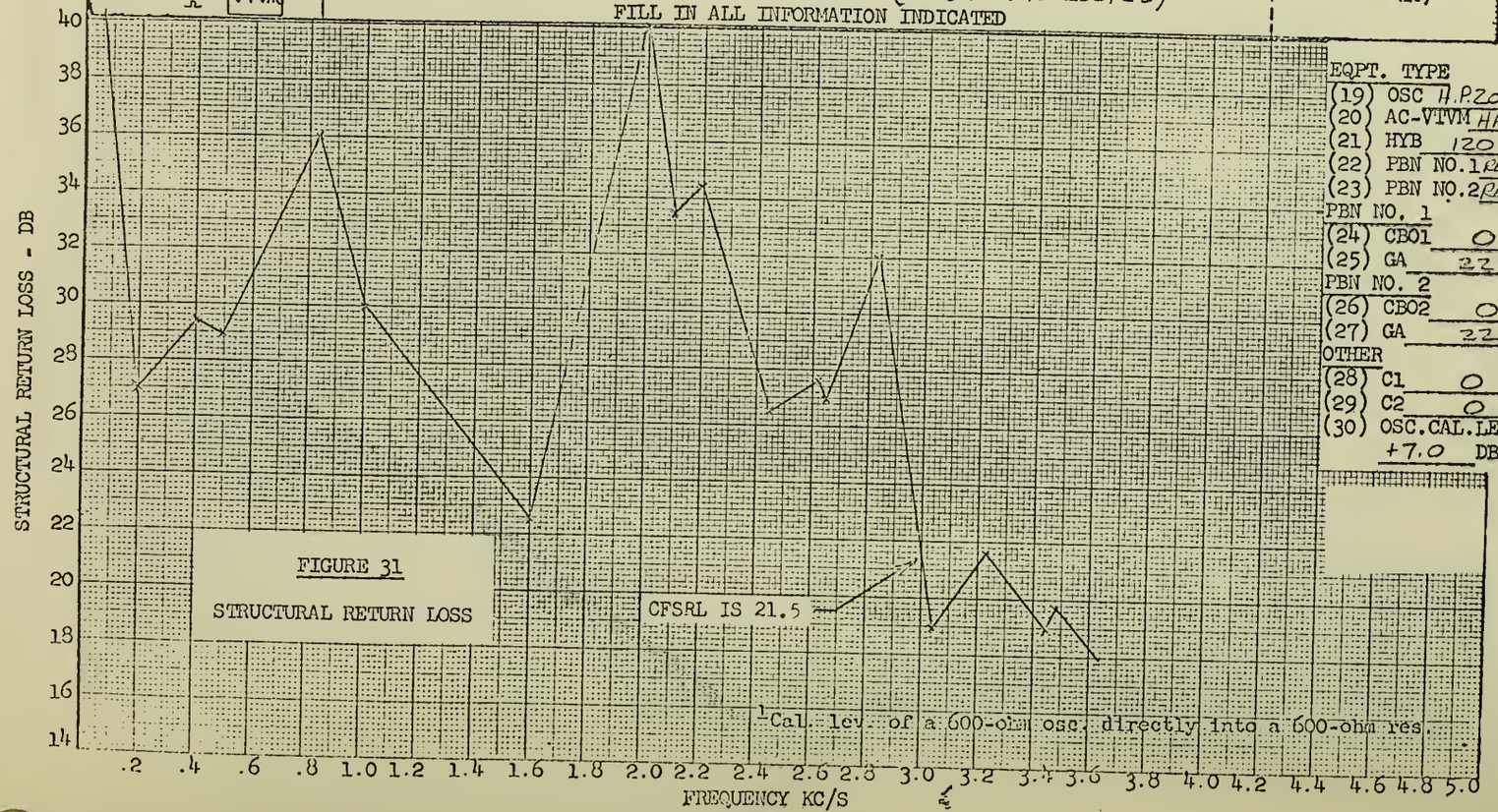


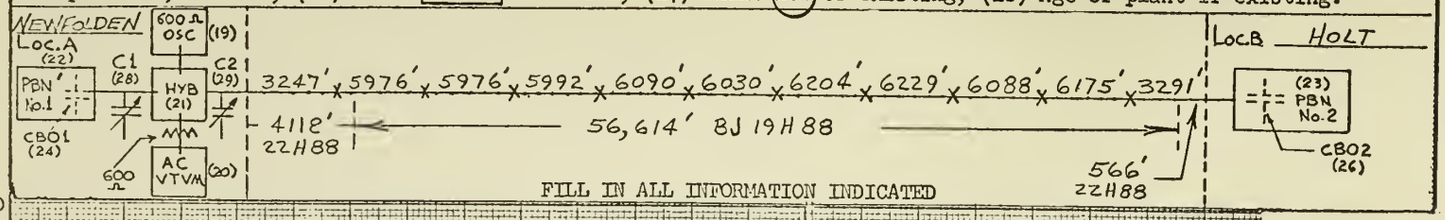
FIGURE 31

STRUCTURAL RETURN LOSS

[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR H-88 LOADING

(1) REA PROJ. DESIGN. MINN. 520 WIKSTROM (2) TRK.GROUP NEWFOLDEN TO HOLT (3) TOLL, FAS, SPEC. (Circle One)
(4) MEASURING BETWEEN NEWFOLDEN TO HOLT (5) TRUNK NO. LOC. A ___, LOC. B ___ (6) PAIR NO. LOC. A 13, LOC.B 32
(7) TEMP. AIR ____ °F (IF Aerial), GD. 40 °F (If Buried) (8) TESTERS PGL, JHP (9) DATE MEASMS. 2/13/62
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant buried or aerial, (17) Plant new or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

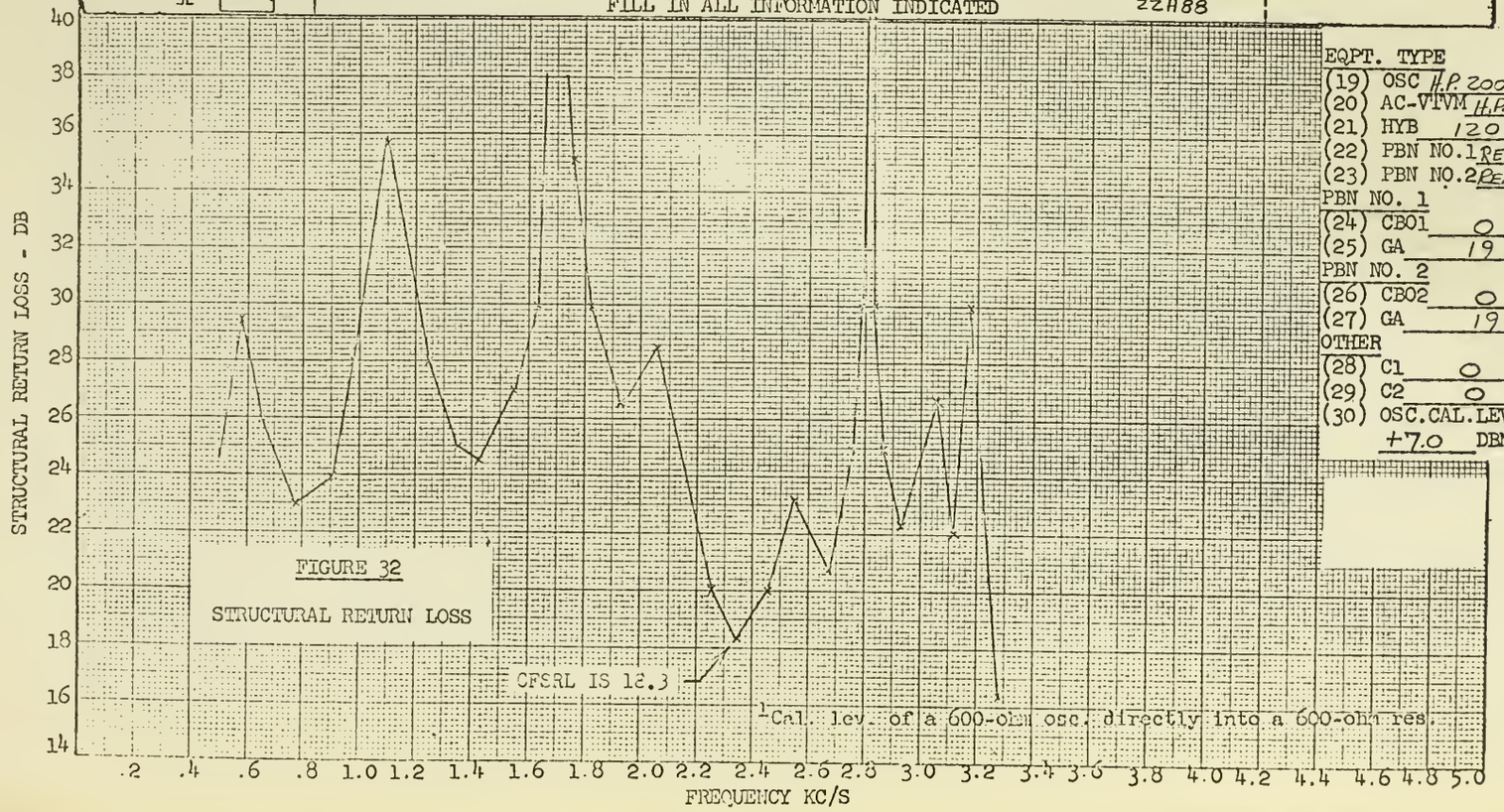


FIGURE 32

STRUCTURAL RETURN LOSS

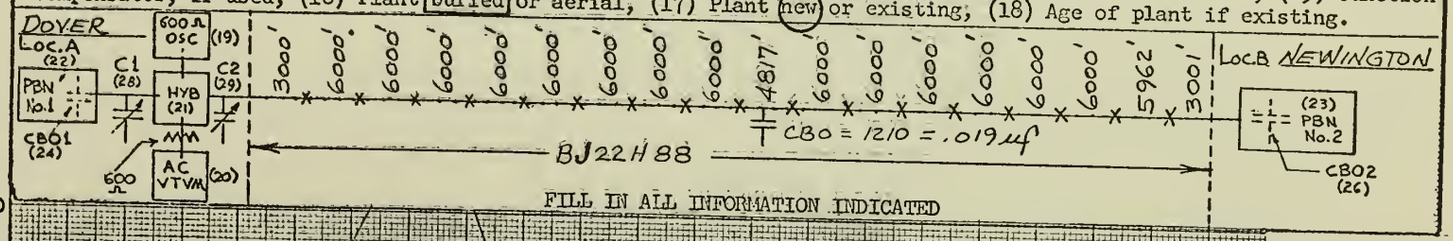
EQPT. TYPE
(19) OSC H.P 200 CD
(20) AC-VTVM H.P 400D
(21) HYB 120P
(22) PBN NO.1 REA-H-88
(23) PBN NO.2 REA-H-88
PBN NO. 1
(24) CBO1 0 MF
(25) GA 19
PBN NO. 2
(26) CBO2 0 MF
(27) GA 19
OTHER
(28) C1 0 MF
(29) C2 0 MF
(30) OSC.CAL.LEV.[1] +7.0 DBM

[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

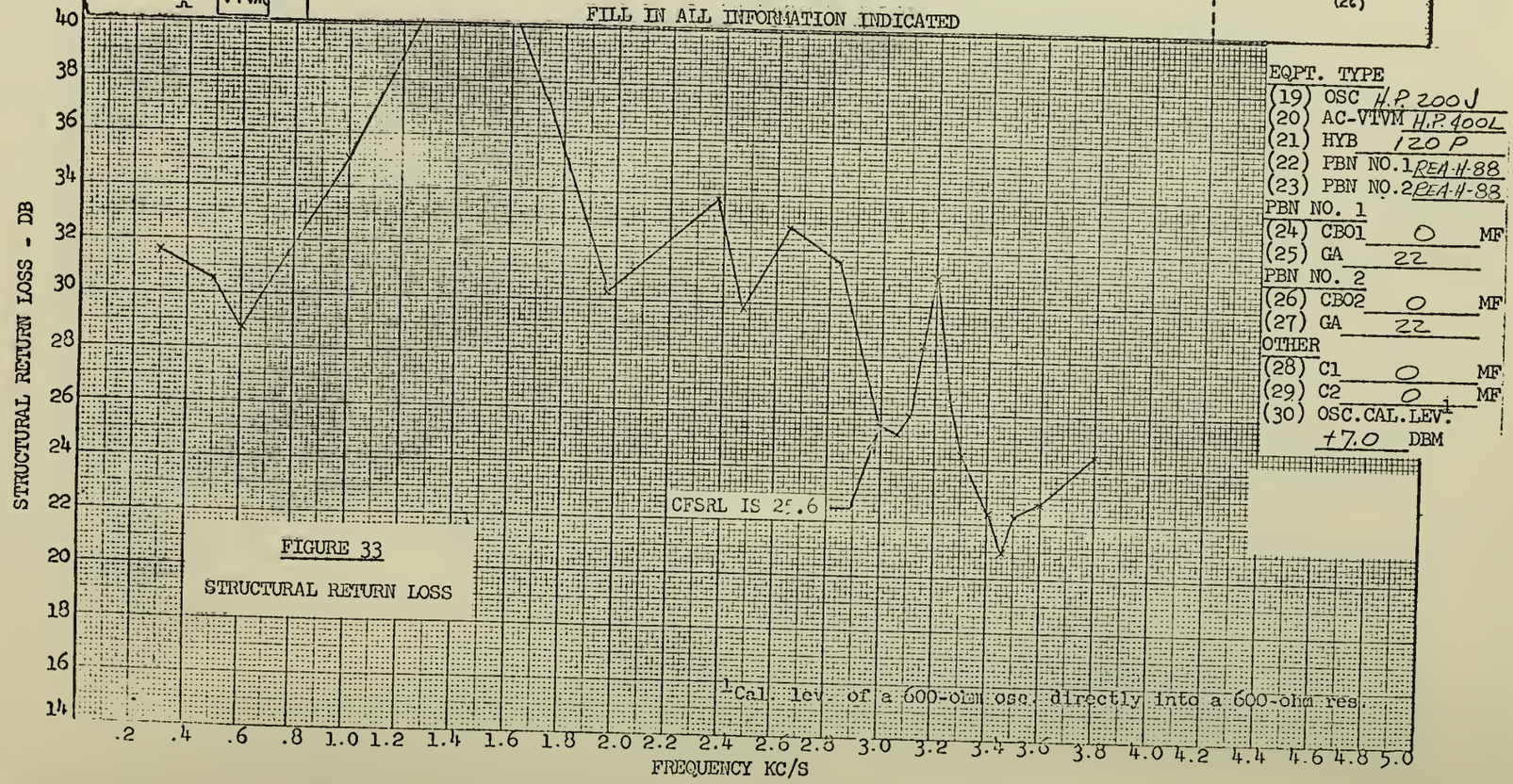
FIGURE 21- Drainage Unit

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR H-88 LOADING

(1) REA PROJ. DESIGN. GA. 534 PLANTERS (2) TRK.GROUP DOVER TO NEWINGTON (3) TOLL, (EAS) SPEC. (Circle One)
(4) MEASURING BETWEEN DOVER TO NEWINGTON (5) TRUNK NO. LOC. A 3, LOC. B 3 (6) PAIR NO. LOC. A 3, LOC.B 3
(7) TEMP. AIR _____ °F (IF Aerial), GD. ____ °F (If Buried) (8) TESTERS RGL, TJM (9) DATE MEASMS. 10/25/62
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED



EQPT. TYPE
(19) OSC H.P 200J
(20) AC-VTVM H.P 400L
(21) HYB 120 P
(22) PBN NO.1 REA-H-88
(23) PBN NO.2 REA-H-88
PBN NO. 1
(24) CBO1 0 MF
(25) GA 22
PBN NO. 2
(26) CBO2 0 MF
(27) GA 22
OTHER
(28) C1 0 MF
(29) C2 0 MF
(30) OSC.CAL.LEV[1] +7.0 DBM

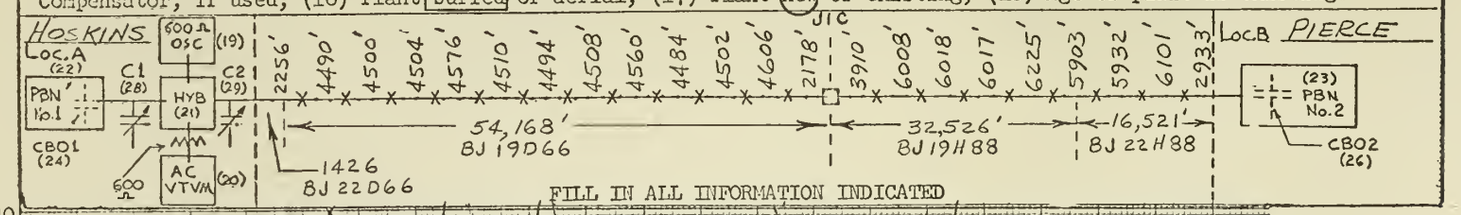
FIGURE 33

STRUCTURAL RETURN LOSS

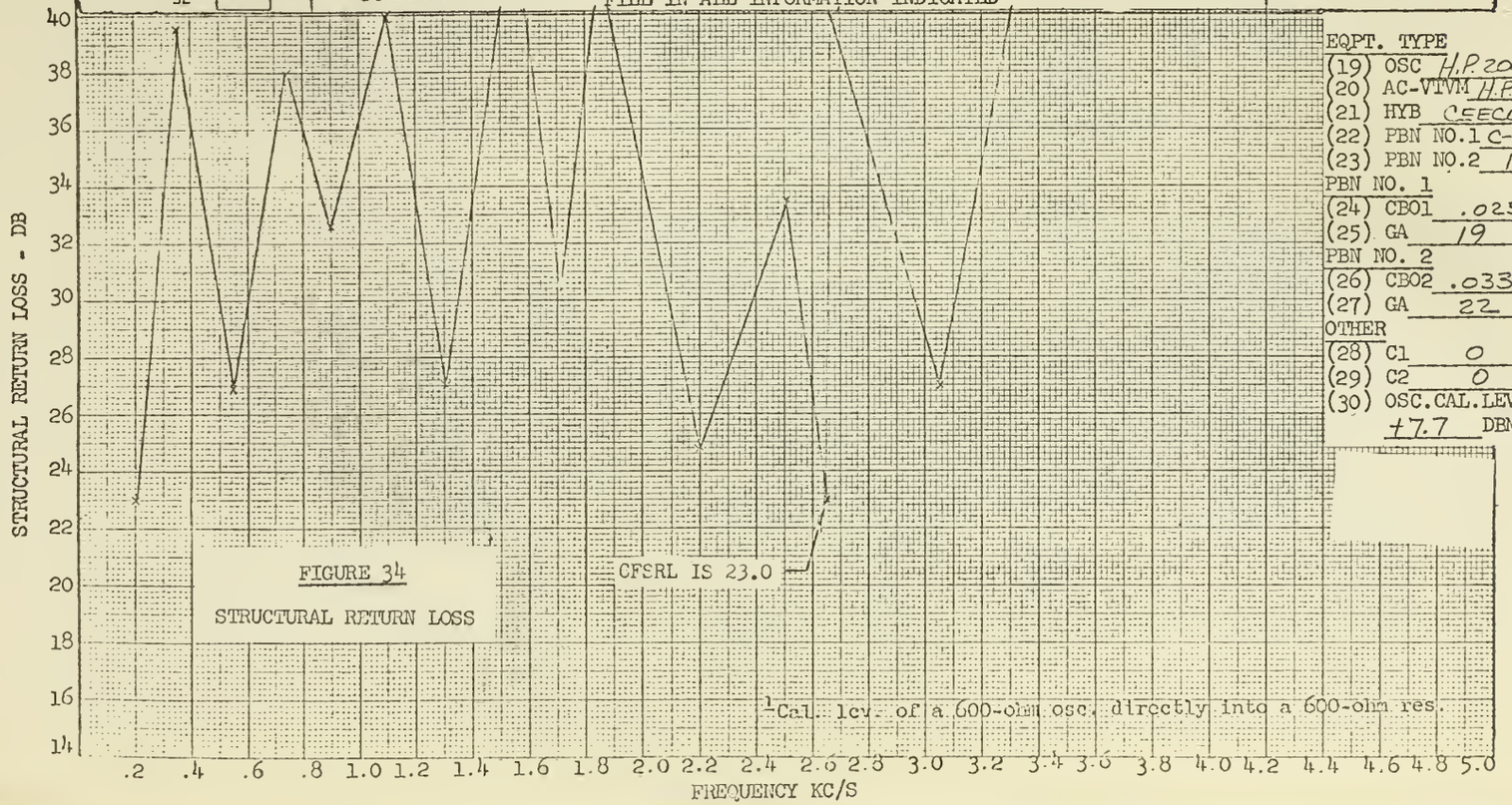
[1] Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR H-88 LOADING

(1) REA PROJ. DESIGN. NEBRASKA 536 B (2) TRK.GROUP HOSKINS TO PIERCE (3) TOLL, (FAS) SPEC. (Circle One)
(4) MEASURING BETWEEN HOSKINS TO PIERCE (5) TRUNK NO. LOC. A 1, LOC. B 1 (6) PAIR NO. LOC. A 151, LOC. B 276
(7) TEMP. AIR 25 °F (IF Aerial), GD. 45 °F (If Buried) (8) TESTERS RAC, HA, FS. (9) DATE MEASMS. 2/6/64
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant [buried] or aerial, (17) Plant (new) or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED



EQPT. TYPE
(19) OSC H.P. 200 J
(20) AC-VTVM H.P. 400D
(21) HYB GEECO
(22) PBN NO.1 C-115 D
(23) PBN NO.2 115 H
PBN NO. 1
(24) CBO1 .025 MF
(25) GA 19
PBN NO. 2
(26) CBO2 .033 MF
(27) GA 22
OTHER
(28) C1 0 MF
(29) C2 0 MF
(30) OSC.CAL.LEV.[1] +7.7 DBM

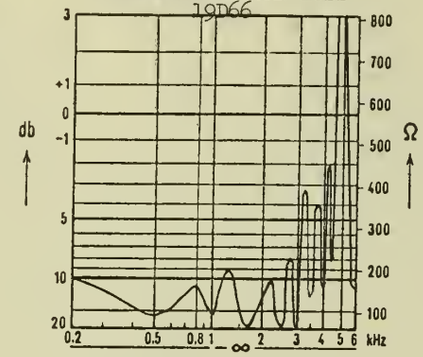
FIGURE 34

STRUCTURAL RETURN LOSS

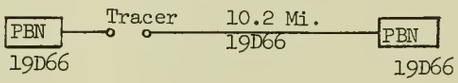
[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

FIGURE 21- Drainage Unit

STRUCTURAL RETURN LOSS
19D66



REA ARTIFICIAL LINES



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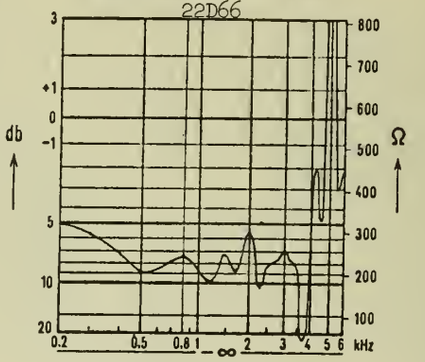
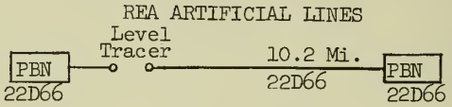
Rec.: -30

STRUCTURAL RETURN LOSS
22D66



REA ARTIFICIAL LINES



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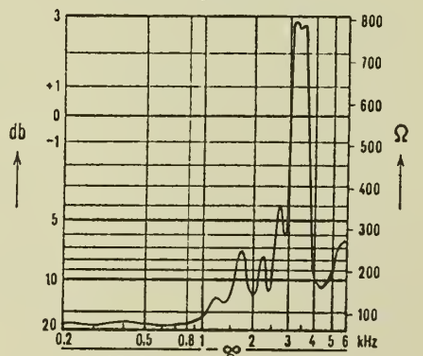
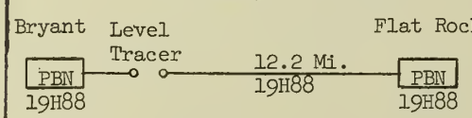
STRUCTURAL RETURN LOSS
19H88



Alabama 528 Farmers



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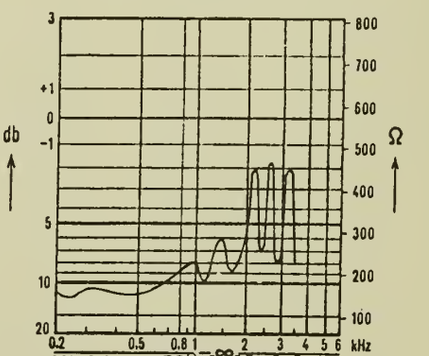
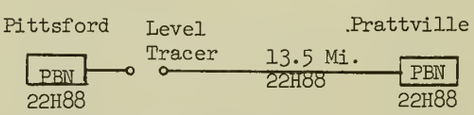
Rec.: -20

STRUCTURAL RETURN LOSS
22H88



Michigan 528 Hillsdale



Send: 0
Rec.: -20

SFSRL USING THE SIEMENS-HALSKE CO. LEVEL TRACER

FIGURE 35

DATA SHEET - ECHO STRUCTURAL RETURN LOSS (ESRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN. IA. 501D (2) TRK.GROUP DOVIS TO POPETOY (3) TOLL, (EAS), SPEC. (Circle One)
(4) MEASURING BETWEEN DOVIS TO POPETOY (5) TEMP. AIR 75 °F (IF Aerial), GD. ___ °F (If Buried)
(6) TESTERS PELEHIK (7) DATE MEASMS. 7/12/63 In line diagram below show: (8) Type of loading system,
(9) All gauges and length of each, (10) As-build length of each full-loading section, (11) As-built length of each end-section, (12) CBO, amount and location, (13) Junction Compensator, if used, (14) Plant buried or aerial,
(15) Plant (new) or existing, (16) Age of plant if existing. EQUIPT. TYPE: (17) NOISE GEN. WE.201E (18) NMS W.E.3A
(19) HYB FIG.9 ALTED (20) PBN NO. 1 FIG.3 (21) PBN NO. 2 FIG.3 PBN No.1: (22) GA 22 PBN No.2: (23) GA 22
OTHER: (24) C1 0 MF (25) C2 0 MF (26) C3 0 MF (27) NOISE GEN. LEVL +7 DBM (Directly into a 600 ohm resistor

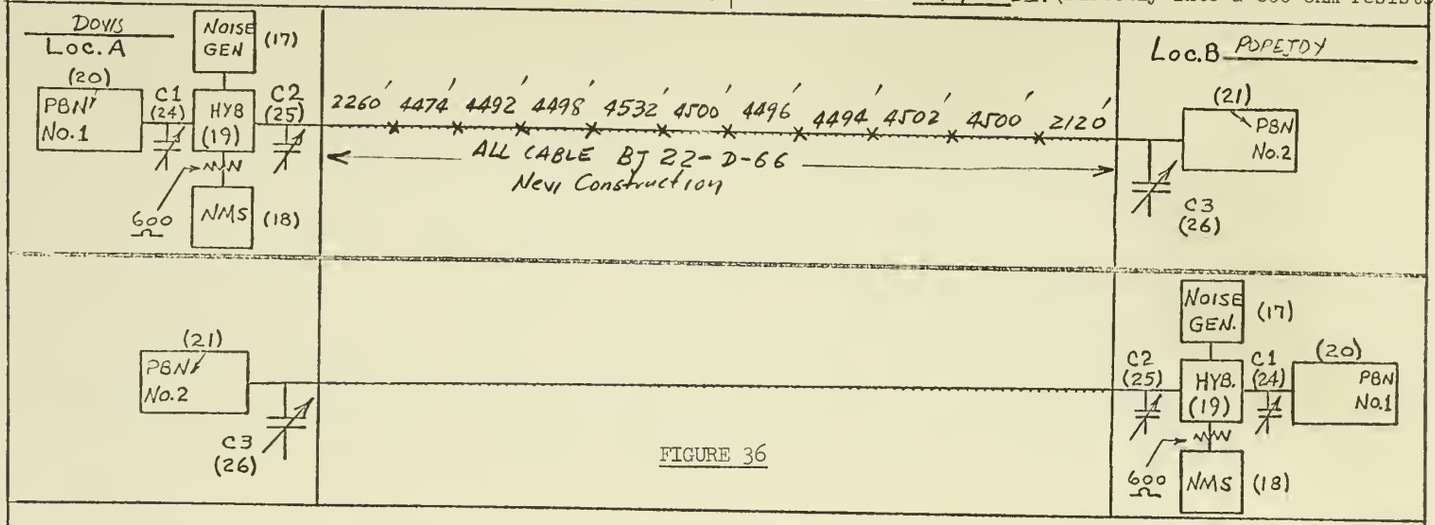


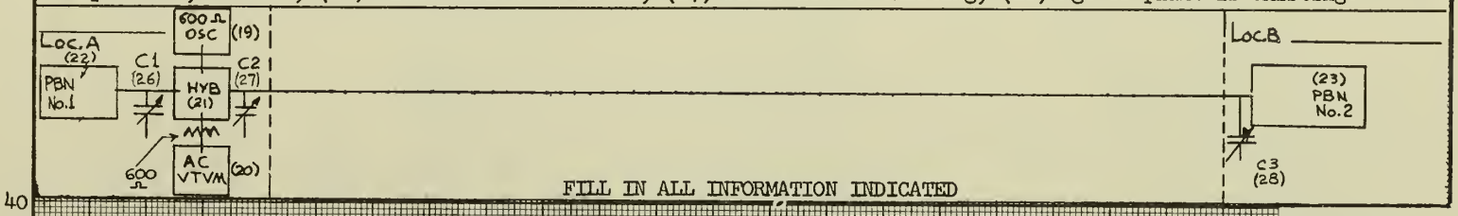
FIGURE 36

TRUNK NO.	PAIR NO. Loc. A	PAIR NO. Loc. B	MEASUREMENT AT LOCATION A ESRL (db)	MEASUREMENT AT LOCATION B ESRL (db)
1	1	1	89 - 52 = 37	NOT MEASURED AT THIS TIME
2	2	2	89 - 53.5 = 35.5	
3	3	3	89 - 50 = 39	
4			NOT MEASURED	
5	5	5	89 - 49.5 = 39.5	
6	6	6	89 - 48 = 41	
7	7	7	89 - 49 = 40	
8	8	8	89 - 50 = 39	

FIGURE 21- Drainage Unit

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR D-66 LOADING

(1) REA PROJ. DESIGN._____ (2) TRK.GROUP_____TO_____(3) TOLL, EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN_____TO_____(5) TRUNK NO. LOC. A___,LOC. B___(6) PAIR NO. LOC. A___,LOC.B___
(7) TEMP. AIR _____°F (IF Aerial), GD.____°F (If Buried) (8) TESTERS _____(9) DATE MEASMS._____
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant buried or aerial, (17) Plant new or existing, (18) Age of plant if existing.



FILL IN ALL INFORMATION INDICATED

STRUCTURAL RETURN LOSS - DB

40 38 36 34 32 30 28 26 24 22 20 18 16 14

.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0

FREQUENCY KC/S

[1]Cal. lev. of a 600-ohm osc. directly into a 600-ohm res.

EQPT. TYPE
(19) OSC
(20) AC-VTVM_____
(21) HYB_____
(22) PBN NO.1_____
(23) PBN NO.2_____

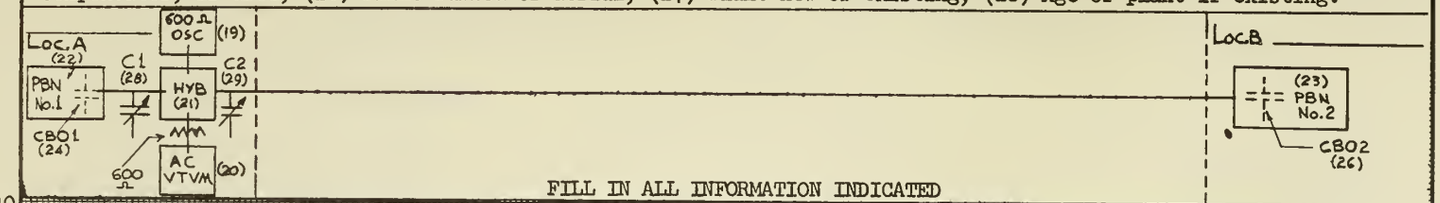
PBN NO.1
(24) GA_____

PBN NO.2
(25) GA_____

OTHER
(26) C_1_____MF
(27) C_2_____MF
(28) C_3_____MF
(29) OSC. OSL. LEV. [1]
_____DBM

DATA SHEET - SINGLE FREQUENCY STRUCTURAL RETURN LOSS (SFSRL) FOR H-88 LOADING

(1) REA PROJ. DESIGN._____ (2) TRK.GROUP_____TO_____(3) TOLL, EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN_____TO_____(5) TRUNK NO. LOC. A___,LOC. B___(6) PAIR NO. LOC. A___,LOC.B___
(7) TEMP. AIR _____°F (IF Aerial), GD.____°F (If Buried) (8) TESTERS _____(9) DATE MEASMS._____
In line diagram below show: (10) Type of loading system, (11) All gauges and length of each, (12) As-build length of each full-loading section, (13) As-built length of each end-section, (14) CBO, amount and location, (15) Junction Compensator, if used, (16) Plant buried or aerial, (17) Plant new or existing, (18) Age of plant if existing.



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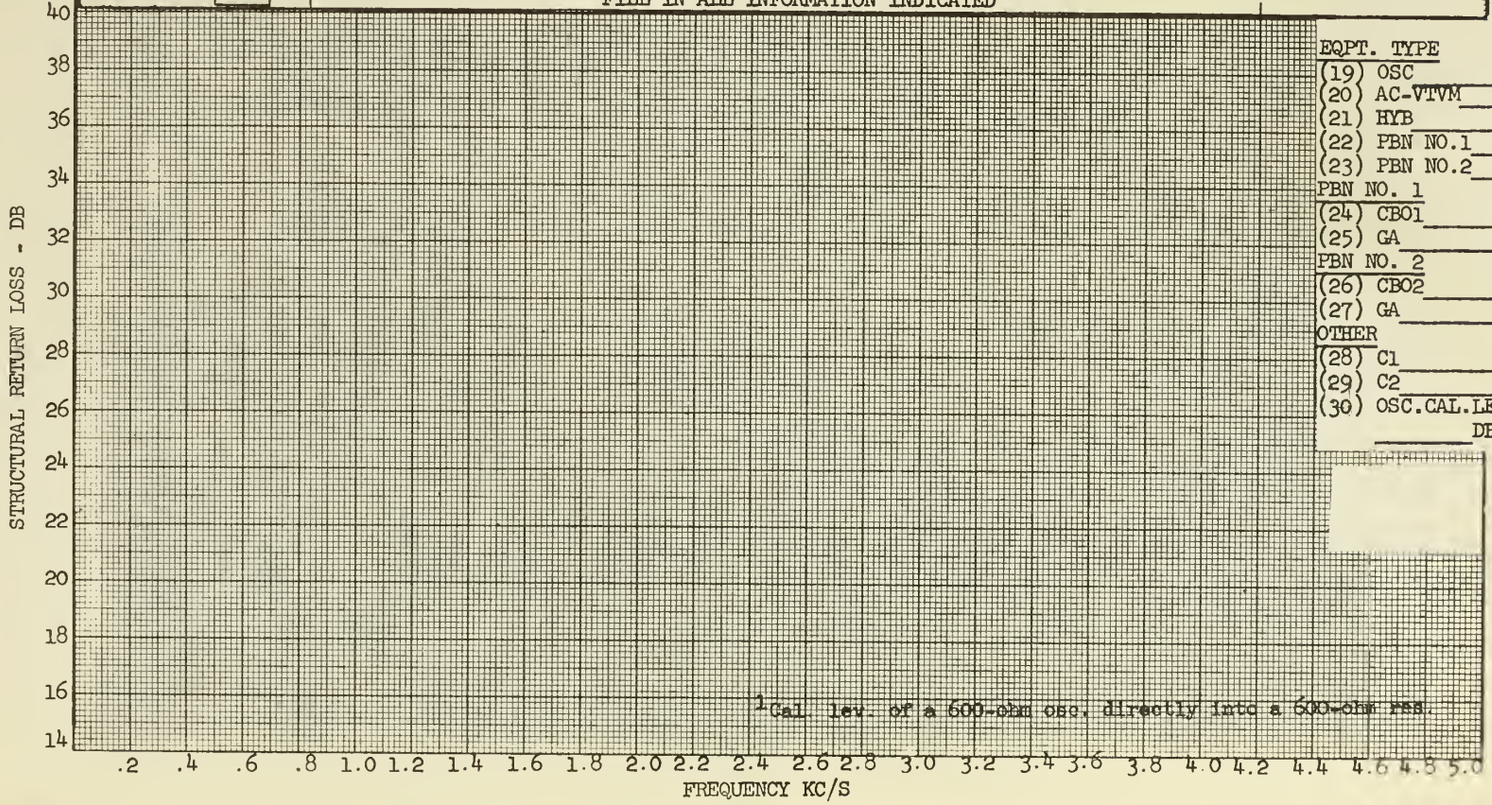


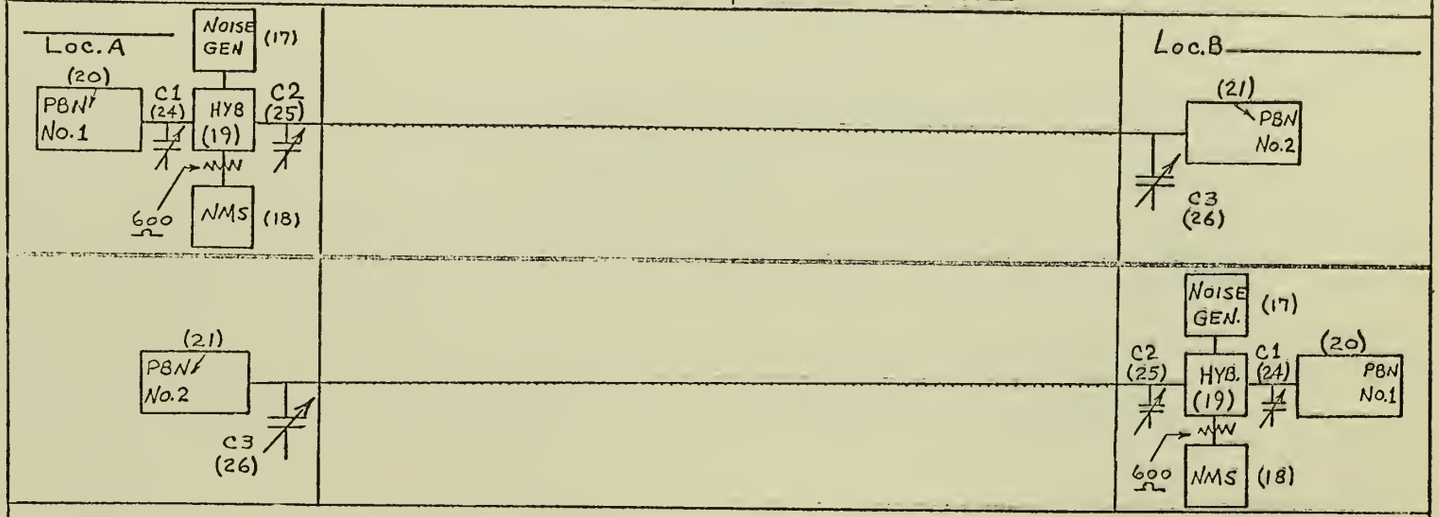
EQPT. TYPE
(19) OSC _____
(20) AC-VTVM _____
(21) HYB _____
(22) PBN NO.1 _____
(23) PBN NO.2 _____
PBN NO. 1
(24) CBO1 _____ MF
(25) GA _____
PBN NO. 2
(26) CBO2 _____ MF
(27) GA _____
OTHER
(28) C1 _____ MF
(29) C2 _____ MF
(30) OSC.CAL.LEV.[1] _____ DBM

[1]Cal lev. of a 600-ohm osc. directly into a 600-ohm res.

FIGURE 20- Insulation Resistance
FIGURE 21- Drainage Unit

DATA SHEET - ECHO STRUCTURAL RETURN LOSS (ESRL) FOR D-66 LOADING

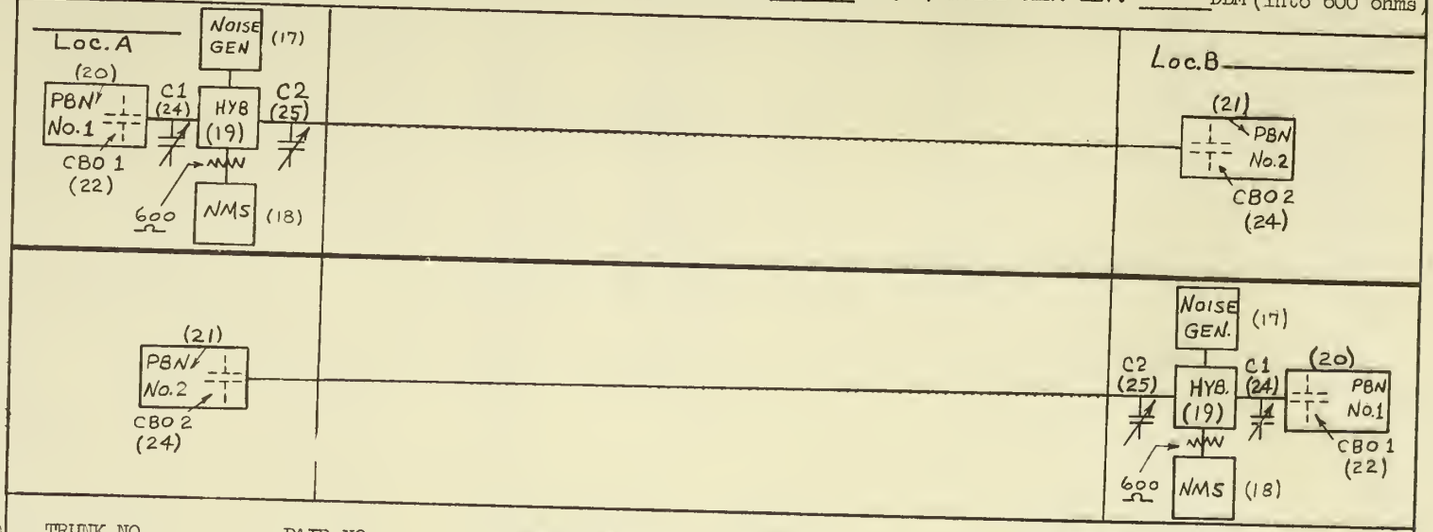
(1) REA PROJ. DESIGN._____(2) TRK.GROUP_____TO_____(3) TOLL, EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN_____TO_____(5) TEMP. AIR_____°F (IF Aerial), GD._____°F (If Buried)
(6) TESTERS_____(7) DATE MEASMS._____ In line diagram below show: (8) Type of loading system, (9) All gauges and length of each, (10) As-build length of each full-loading section, (11) As-built length of each end-section, (12) CBO, amount and location, (13) Junction Compensator, if used, (14) Plant buried or aerial, (15) Plant new or existing, (16) Age of plant if existing. EQUIPT. TYPE: (17) NOISE GEN._____(18) NMS_____
(19) HYB_____(20) PBN NO. 1_____(21) PBN NO. 2_____ PBN No.1: (22) GA_____ PBN No.2: (23) GA_____
OTHER: (24) C1_____MF (25)C2_____MF (26) C3_____MF (27) NOISE GEN. LEVL_____DBM (Directly into a 600 ohm resistor)



TRUNK NO.	PAIR NO.		MEASUREMENT AT LOCATION A	MEASUREMENT AT LOCATION B
	Loc. A	Loc. B	ESRL (db)	ESRL (db)

DATA SHEET - ECHO STRUCTURAL RETURN LOSS (ESRL) FOR H-88 LOADING

(1) REA PROJ. DESIGN._____(2) TRK.GROUP_____TO_____(3) TOLL, EAS, SPEC. (Circle One)
(4) MEASURING BETWEEN_____TO_____(5) TEMP. AIR_____°F (IF Aerial), GD.____°F (If Buried)
(6) TESTERS_____(7) DATE MEASMS._____ In line diagram below show: (8) Type of loading system, (9) All gauges and length of each, (10) As-build length of each full-loading section, (11) As-built length of each end-section, (12) CBO, amount and location, (13) Junction Compensator, if used, (14) Plant buried or aerial, (15) Plant new or existing, (16) Age of plant if existing. EQUIPT. TYPE: (17) NOISE GEN._____(18) NMS_____ (19) HYB_____(20) PBN NO. 1_____(21) PBN NO. 2_____ PBN NO. 1:(22) CBO1_____MF (23) GA____ PBN NO. 2: (24) CBO2_____MF (25) GA____ OTHER:(26) C1_____MF (27) C2_____MF (28) NOISE GEN. LEV. _____DBM (Into 600 ohms)



TRUNK NO.	PAIR NO.		MEASUREMENT AT LOCATION A	MEASUREMENT AT LOCATION B
	Loc. A	Loc. B	ESRL (db)	ESRL (db)

FIGURE 20- Isolation Transformer
FIGURE 21- Drainage Unit

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BOOK STACKS - DOCUMENTS

TELEPHONE NOISE MEASUREMENT AND MITIGATION

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1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to provide an understanding of noise in the telecommunications network. Techniques for measurement, analysis, isolation and solution of noise problems will be discussed in subsections. Discussion will be directed primarily to 60 Hertz and its harmonics and their effects on the telephone system.

1.2 This revision replaces REA TE&CM 451, Issue No. 1, dated November 1965 and is reissued to reflect advances in the state of the art of noise measurement and mitigation.

1.3 Power companies today are confronted with an increasing load demand. Telephone companies are utilizing more electronic equipment in their plant operations. Both power and telephone companies are under economic and environmental pressure to use joint right-of-ways. It is essential that inductive coordination problems be resolved from an overall system approach so that advantages of joint random plant and shared rights-of-way may be achieved. If maximum compatibility is to be realized, the telephone engineer will need an understanding of power system problems and the power engineer will need an equal understanding of telephone system problems.

1.4 There is always some noise present on telephone lines. In very small amounts it may be undetected while in slightly greater amounts it becomes annoying to the telephone user. Greater amounts will degrade transmission performance and, in more severe cases, noise can render a connection unusable for conversation. Any disturbance which interferes with the reception of desired sounds by the human ear is noise. Telephone line noise is becoming an increasing problem as demands for power and telephone services grow resulting in additional emphasis by the telephone industry toward its control. There is also usually some longitudinal induced 60 Hertz voltage present on telephone lines. Depending on the magnitude this can produce equipment and personnel safety problems. (See paragraph 3.27).

1.5 Overall noise in a circuit may be a combination of different types of noise, each from a different source. Several of these are outlined in Paragraph 2. This section, as noted in Paragraph 1.1, is primarily concerned with the noise induced by harmonics from 60 Hertz power lines. Induced noise from power lines is the predominant type experienced in telephone lines. No attempt is made herein to discuss in detail the various other types of noise. Some of the more prominent of these can be controlled by proper equipment design and good maintenance procedures. They are, therefore, discussed in the appropriate sections of the engineering manual.

1.6 Impulse noise is receiving more attention in the telephone industry because of its effect on data transmission. Amounts greater than a threshold value produce errors. This type of noise is characterized by a very short time duration and large amplitude. Whereas power line harmonics produce a steady audible sound similar to hum it is, therefore, often referred to as "power line hum", impulse noise does not produce an audible sound. For this reason the effect of impulse noise is not as critical for normal speech transmission as it is for data (transmission of information in pulse form). Impulse noise objectives are given in TE&CM Section 415 but the treatment of circuits for conditioning to data will be included in a separate section of the engineering manual.

1.7 High voltage dc transmission (HVDC) lines are operating or planned in various parts of the country. These have the capability of handling to 2000 megawatts of electric power (at $\pm$ 400 kV during bipolar operation). Due to their close relationship with the 60 Hertz power system, the noise contribution associated with these systems will be discussed in TE&CM Section 451.6.

1.8 The analysis of noise problems cannot be approached in a haphazard manner. The many factors which can contribute to noise in telephone systems can cause considerable confusion in the analysis of noise problems if they are not properly isolated and remedial action taken in the proper sequence.

1.81 It is essential that a systematic procedure be followed and the specific tests made in the proper sequence during a noise investigation. It is wise to never take anything as fact which has not been proven by measurement when working with noise. In the absence of a systematic procedure, time can be wasted and often a solution will not be found.

1.82 Noise problems in telephone systems can be complex but in many cases the solutions to these problems can be simple and within the capability of craftspeople. A flow chart for noise investigation procedures is included in Appendix A.

2. TYPES OF NOISE

2.1 Although this section is devoted primarily to noise from power line harmonics, other types cannot be completely ignored because the order of magnitude for overall noise considered acceptable depends to some extent on these. The noise of greatest intensity tends to mask out the others. Voice frequency noise may be of either acoustic or electrical origin.

2.2 Acoustic Types of Noise

2.21 Room noise entering the telephone transmitter and reaching the receiver through the sidetone path.

2.22 Room noise entering the telephone transmitter and transmitted in the same manner as speech.

2.3 Electrical Types of Noise

2.31 Electrical Storms

2.32 Inadequate battery filtering.

2.33 Contact noise in switching apparatus.

2.34 Noise from electronic equipment.

2.35 Unintelligible crosstalk from other telephone circuits

2.36 Noise induced from power lines.

3. SIGNIFICANT FREQUENCY COMPONENTS

3.1 Most ac power lines in the United States have a fundamental frequency of 60 Hertz, and the bulk of energy is transmitted at this desired frequency. For reasons discussed later, the alternating voltage or current is never a pure 60 Hertz sine wave, but contains harmonics which extend into the voice frequency range. The magnitude of these harmonic components is small compared to that of the fundamental frequency. Because the telephone set and the characteristics of the human ear are far more sensitive in the range of the harmonic frequencies and furthermore because inductive coupling efficiency increases with frequency, the harmonics are of greater importance to the telephone system than the fundamental frequency component.

3.2 There is also induction at the fundamental frequency called "low frequency induction." Low frequency induction is normally a protection and safety consideration, rather than a noise problem, because of the transmission characteristics of the telephone set and the human ear both of which attenuate these lower frequencies.

3.21 An induced fundamental frequency voltage of fifty volts is the maximum permissible on a cable pair (See paragraph 12.6(a)). This level is related to personnel safety. Signaling problems can occur with fundamental frequency voltages of lower magnitude. Some electronic equipment can become noise sources with relatively low levels of 60 Hertz voltage (10 to 15 volts).

3.22 Longitudinal voltages in excess of 50 volts are becoming more commonplace as the demands for power increase. Where excessive fundamental frequency voltage exists it should be reduced before proceeding further with any noise investigation. (See paragraph 15).

3.3 Induction at frequencies which are harmonics of 60 Hertz is termed "harmonic induction" or "noise frequency induction" and this section is primarily devoted to this type of noise induction. The range of harmonic frequencies which may become involved in noise problems can be from 180 to approximately 4000 Hertz. This represents a range from the third to the 67th harmonic of the 60 Hertz fundamental frequency.

3.4 The human ear is sensitive only to frequencies in a range of approximately 20 to 20,000 Hertz, but is not equally sensitive to sounds of equal intensities at all frequencies in this range. It is most sensitive, on the average, to frequencies of about 2000 Hertz. The variation in sensitivity is somewhat in accordance with the following, shown in Table I, (for average young people).

TABLE I

Frequency in Hertz	Minimum Acoustic Pressure in dBRAP for Perception
20	80
60	43
100	32
200	18
300	14
400	11
500	7
1000	3
2000	-3
5000	-5

3.41 The above table indicates that a sound at 60 Hertz would have to be about 40 dB higher than one at 1000 Hertz for minimum perception in both cases. Obviously, one of the measures of the disturbing effect of noise is its frequency composition, in addition to its intensity. Reference Acoustic Pressure (RAP) is a measure of sound level. Zero dBRAP is 0.0002 dynes per square centimeter in a plane wave. There is an upper limitation as to how loud a sound can be before it becomes painful to the subject and is not perceived as sound in the ordinary sense.

3.42 Like the human ear, the telephone set has a receiving characteristic (weighting) which is a function of frequency. The line connecting to the telephone set tends to modify this characteristic. Figure 1 shows the weighting effect as it applies to the 500 type telephone set.

This curve is the present standard[1] for measuring noise and is termed "C-Message Weighting" to distinguish it from other weighting standards used in the past.

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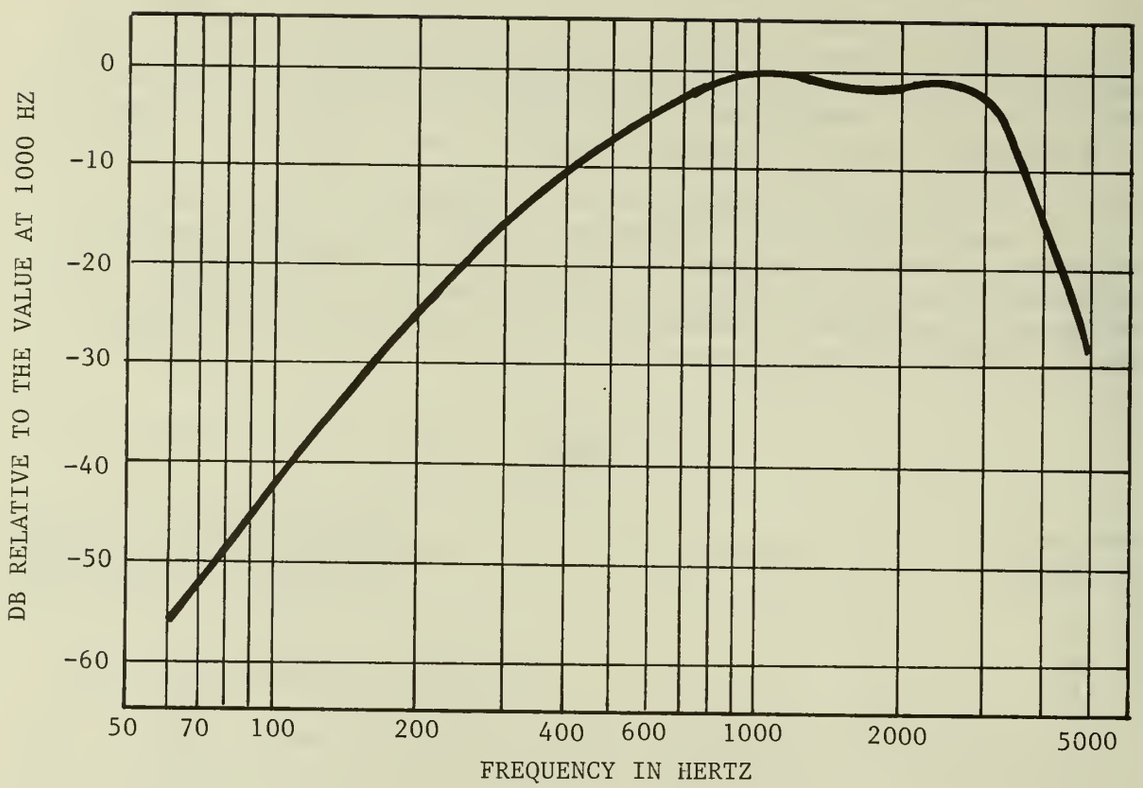
[1]Evaluation of Message Circuit Noise, Bell System Technical Journal, July 1960, pp. 879-909.



RESPONSE IN DECIBELS INDICATING RELATIVE INTERFERING EFFECT, C-MESSAGE WEIGHTING

FIGURE 1

3.421 An examination of this curve reveals the following:

At the frequencies of 180, 360 and 540 Hertz, for example, the reaction by a subscriber using a 500 type telephone set will be such that he hears these frequencies less loud by 27.5, 16.5 and 6 dB, respectively than had the frequency been 1000 Hertz and of the same magnitude. Stated in a different way, if the individual frequencies of 180, 360 and 540 Hertz are to produce the same stimulus (psychological reaction to the listener) as a 1000 Hertz tone, they must be increased in level by 27.5, 16.5 and 6 dB compared to the level of the 1000 Hertz reference tone. This illustrates that different frequencies have different effects on hearing when using a 500 type telephone set. When applied to noise, this means that some harmonic frequencies have more interfering effect than others. Therefore, even a very small amount of a particular harmonic could be sufficient to cause noisy conditions. The interfering effect of the different frequencies for equal loudness is the basis of any weighting curve (bandpass filter) which is used to measure overall circuit noise. As indicated above, the present standard is C-message weighting and is

used for all noise work in both exchange and toll plant. Basis of reference and use of the C-message weighting is further discussed in paragraph 9.2.

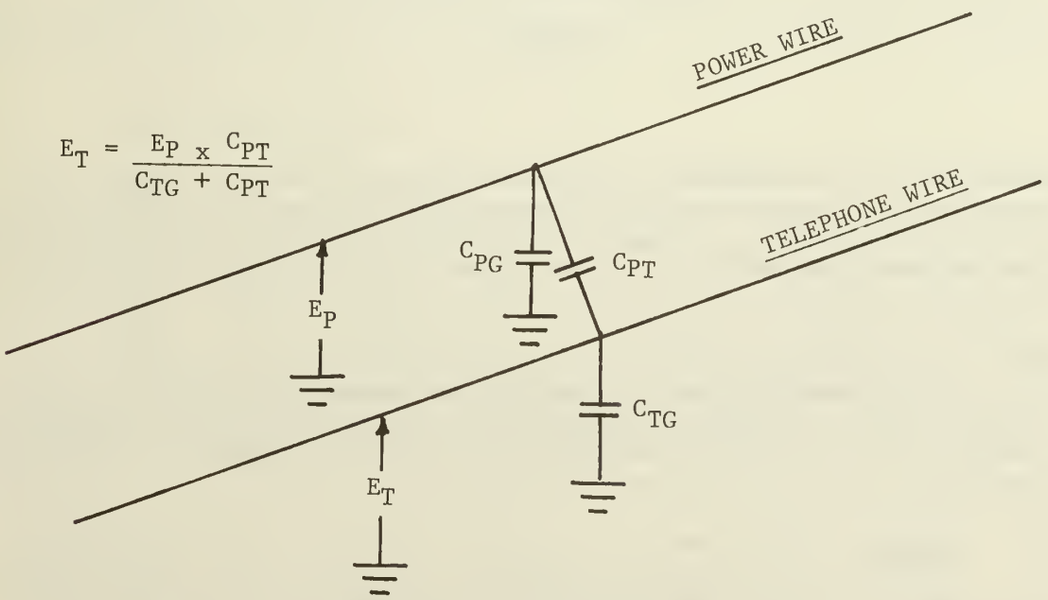
4. THEORY OF COUPLING

4.1 Historically the process of noise induction has been considered in two categories, electric and magnetic fields from the voltages and currents of the power line, respectively. Their effects need to be considered separately, particularly in the analysis of specific problems, because the actions of voltages and currents from an induction standpoint can be different. Power circuit voltages and currents are also affected differently by changes in conditions. The division of the two categories also coincides with different techniques for mitigating effects of the two sources.

4.2 Before discussing some of the more detailed aspects of noise induction, a brief examination of the general nature of electrical and magnetic induction will be covered. An understanding of how these couplings introduce noise on telephone circuits will be valuable in the analysis of specific noise problems.

4.3 Electric Induction

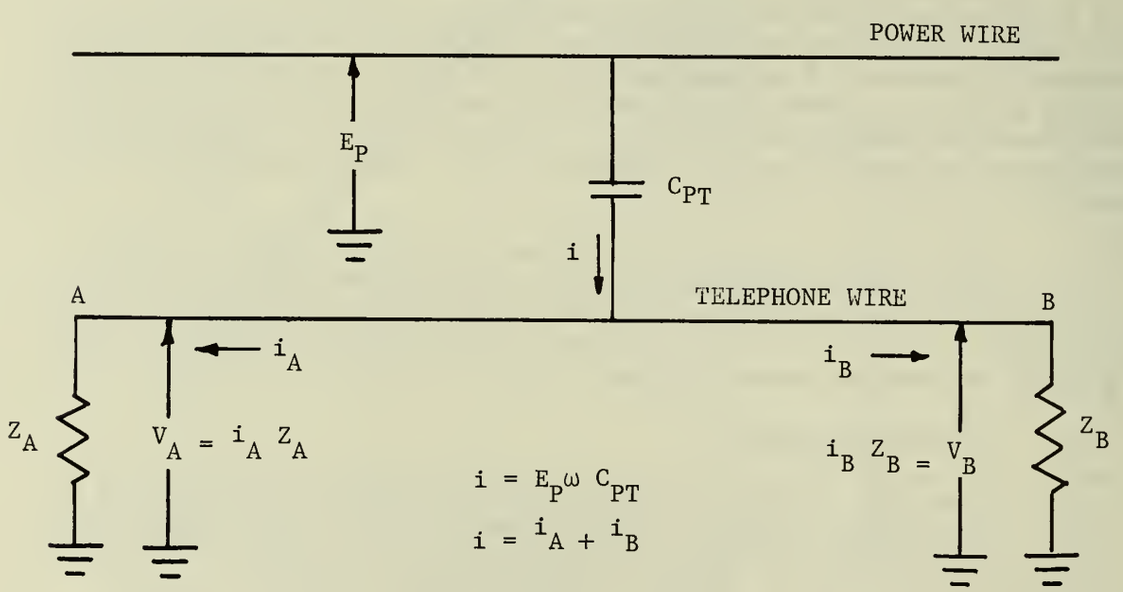
4.31 Electric induction, normally associated with the voltage on a power line may be visualized by means of the capacitance between a single power wire and a single telephone wire. This relationship is illustrated in Figure 2. Induced voltage between the power wire and ground (E_P) divides over the capacitances between the power and telephone wire (C_{PT}) and the telephone wire and ground (C_{TG}) in proportion to their impedances (in inverse ratio to their capacitances). Voltage on the telephone wire (E_T) is expressed by the relation:



ELECTRIC INDUCTION

FIGURE 2

4.32 A different method of visualizing the effects of electric induction is shown in Figure 3 for the practical case where the telephone wire is terminated longitudinally in office equipment or is long enough to be effectively terminated in the characteristic impedance of the circuit.



ELECTRIC INDUCTION

Telephone Wire
Terminated In Its
Characteristic Impedance

FIGURE 3

Impedance of the capacitance (C_{PT}) is much greater than the impedances terminating the telephone wire, and hence the current, "i", is practically independent of Z_A and Z_B. However, the division of the total induced current between the ends of the line depends on the relation between the impedances at A and B.

4.33 Voltage-to-ground due to electric induction is the product of the current i_A and the impedance to ground Z_A or the current i_B times Z_B. Since the value of C_{PT} is directly proportional to frequency, the value of i will be directly proportional to the frequency of the power voltage.

4.34 Summary: The effects of electric induction are directly proportional to the voltage-to-ground on the power wire, the frequency of this voltage, and the length of exposure between the power and telephone wires. It is also proportional to the proximity of the lines (C_{PT} per unit length). Where the telephone plant utilizes shielded cables that

are adequately grounded, the shield has the effect of discharging the capacitance. Pairs contained within the shield are virtually immune to capacitance coupling (electric induction). This form of coupling is still of importance where there is open wire plant.

4.4 Magnetic Induction

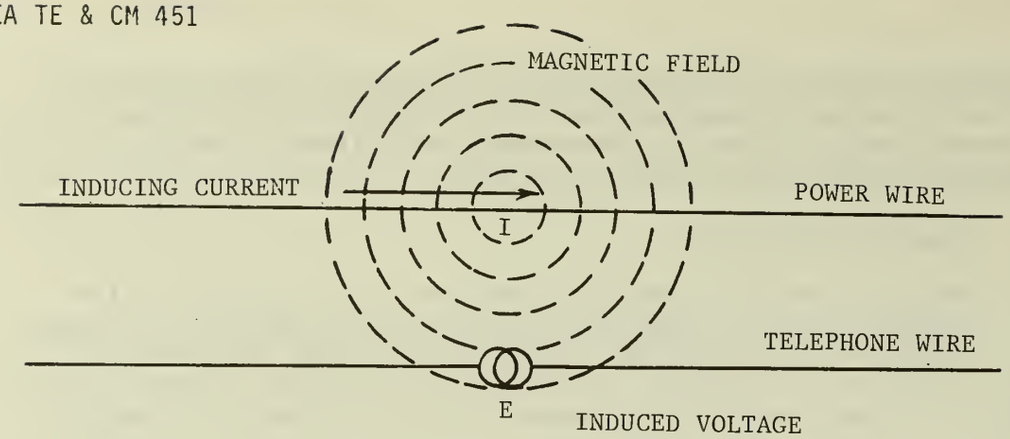
4.41 Magnetic induction, on the other hand, is a function of the current flowing in the power system and is therefore of primary concern. Figure 4 shows that the current in the power wire sets up a magnetic field which alternates at the frequency of the inducing current. A voltage is induced along the telephone wire which is proportional to the rate of change of the magnetic flux just as a secondary winding in a transformer has a voltage induced along it. Figure 5 illustrates how the entire magnetically induced voltage appears between the open end of the telephone line and ground. Figure 6 shows how the voltage-to-ground at each end of a terminated telephone line depends on the terminating impedances and the total magnetically induced voltage (E).

4.42 Where the telephone plant utilizes shielded cables both the shield and the pairs inside are exposed to the flux generated by the power line. Hence, both will have induced voltage. This occurs whether the telephone plant be located above or below the ground. Completion of the shield circuit by grounding at both ends allows a current to flow. This current flow will induce a counteracting voltage on the telephone pairs within the cable shield which tends to cancel some of the original induced voltage. Fundamental frequency cancellation is small. As frequency increases so does the cancellation. This will be discussed in detail in Paragraph 5, "Shielding".

4.43 Summary: Magnitude of the induced voltage is directly proportional to the power line current, to the coupling between the power and telephone lines (which is proportional to the exposure length) and to the frequency of the power line.

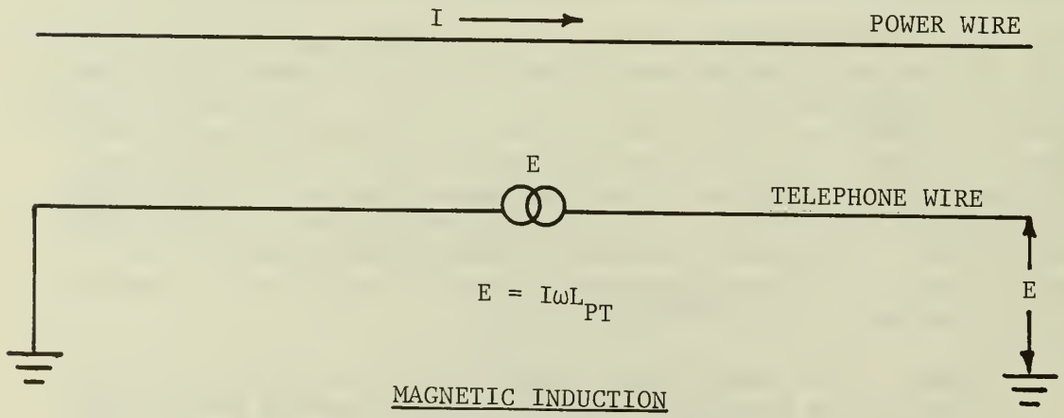
4.5 Conductive Coupling

4.51 There is a form of coupling which is dependent on current flow through the earth. The majority of power systems in the United States use a multigrounded neutral (MGN) conductor. This provides an alternate path to that provided by the earth for the flow of current back to the source. In these systems current will flow through both the neutral conductor and the earth path. The division of current is determined by the characteristics of the particular power system and associated grounds. As much as 60 percent of the current may normally return through the earth with only 40 percent via the neutral conductor. There are still a few power systems operating with a unigrounded "Y" configuration (See paragraph 7.32). In such systems there is no current flow through the ground path.



MAGNETIC INDUCTION

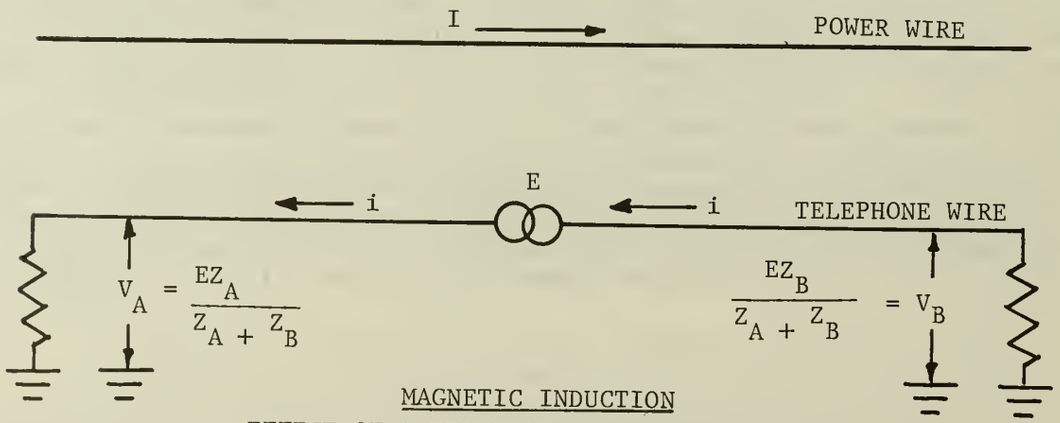
FIGURE 4



MAGNETIC INDUCTION

TELEPHONE WIRE TERMINATED IN ITS CHARACTERISTIC IMPEDANCE

FIGURE 5



MAGNETIC INDUCTION

EFFECT OF A TERMINATED TELEPHONE LINE ON VOLTAGE-TO-GROUND

FIGURE 6

4.52 When earth resistivity is high in the vicinity of power system grounds this earth return current may now divide between the earth path and a telephone cable shield which is grounded near it. This mode of coupling is sometimes referred to a conductive coupling. The current flowing in the shield will induce a voltage on the cable pairs which can result in increased circuit noise. This will be discussed in more detail in paragraph 5, "Shielding".

4.53 Summary: Cable shields carry a portion of the earth or ground return current from the power system. This current flow in the shield will induce a voltage in the cable pairs which can result in noise in the telephone circuits.

5. SHIELDING

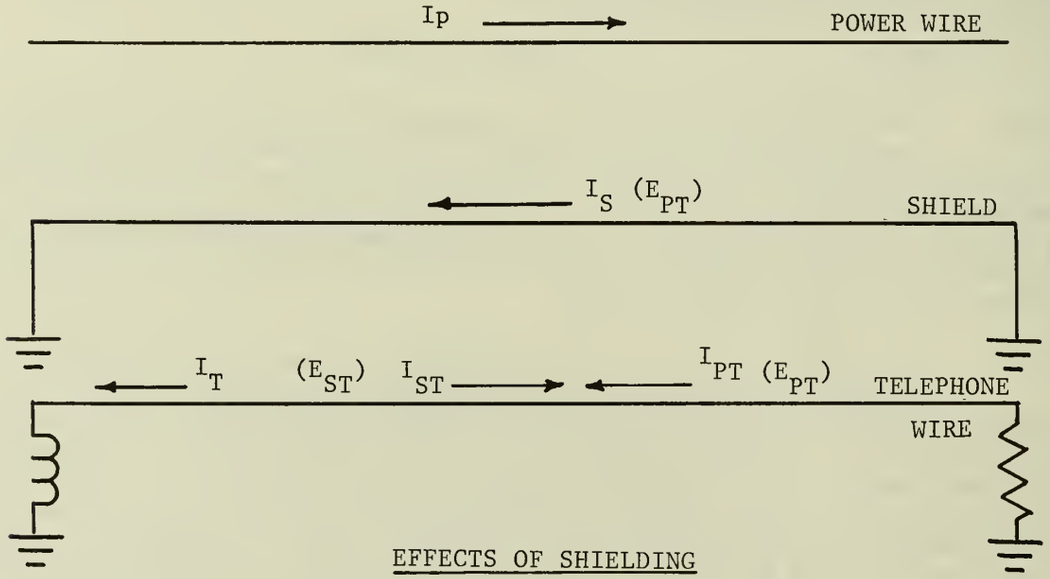
5.1 Examination of the effects of shielding and its relationship to longitudinal induced voltages on a telephone line is important. Shielding can effectively reduce the voltage, especially harmonic voltage, induced in cable pairs when the shield is continuous and effectively grounded along the exposure. In many instances noise problems are a result of inadequate shielding of telephone cables due to lack of continuity rather than power company sources.

5.2 The importance of shield continuity can best be explained by a review of how shielding works. While the entire subject of induction and the shielding function is complex and beyond the scope of this practice a simplified explanation will be sufficient to illustrate its importance. A more detailed discussion of shielding will be presented in TE&CM Section 452. Figure 7 shows that when a current (Ip) flows in a power conductor with earth return, a magnetic field is generated around the conductor. If a telephone cable is located in this field a voltage (Ept) will be induced in the shield and conductors of the telephone cable. The magnitude of voltage (Ept) may be determined for the condition where no shielding exists by calculating the mutual impedance between the power conductor and the telephone cable. Mutual impedance is defined as the voltage per unit length induced in the disturbed conductor (telephone cable shield or conductor) per ampere of current in the disturbing circuit and associated earth return path. Mutual impedance, which will be discussed in detail in TE&CM Section 452, is a complex value based on earth resistivity, frequency and separation between the disturbing and disturbed conductors.

5.21 When the telephone conductor is grounded through a load a current (1_{PT}) will flow through the conductor. This current at any instant is 180^{o} reversed (out of phase) with respect to the power conductor current as shown by the arrow in Figure 7.

5.22 For practical purposes, the cable shield is spaced almost the same distance from the power conductor as the cable conductors. Consequently, it may be assumed the same voltage will be induced on the shield as on the cable conductors. When the shield is grounded at both ends a current (1_{S}) will flow in the shield circuit in the same direction as the current (1_{PT}) in the cable conductors. This current flow with its

associated earth return path will generate a magnetic field and a counteracting voltage (E_{ST}) will be induced on the telephone cable conductors via the mutual impedance between the shield and conductors. This mutual impedance can be defined in simple terms as the voltage per unit length induced in the disturbed telephone cable conductor per ampere of current in the disturbing shield circuit and its associated earth return path. A current (1_{ST}) will flow in the telephone cable conductors due to the induced voltage (E_{ST}) in the opposite direction to that induced from the power system (1_{PT}) as shown by the arrow in Figure 7.



EFFECTS OF SHIELDING

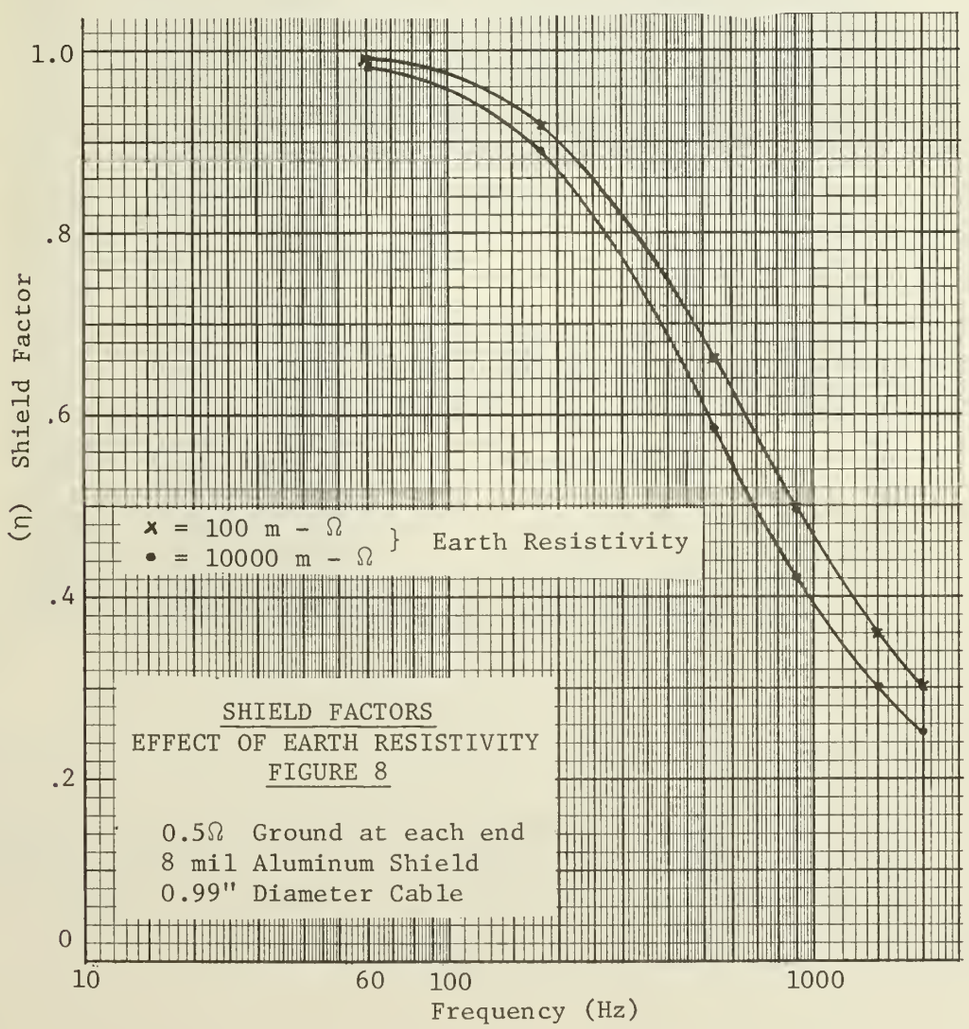
FIGURE 7

5.23 If a voltage equal in magnitude to that induced in the cable conductor from the power conductor could be induced in the cable conductor from the shield total cancellation would result and there would be no noise. The probability of such an ideal state existing in practice is practically nil. The amount of shielding may be expressed as the percentage voltage reduction in the disturbed circuit (telephone cable conductor) resulting from the introduction of a shielding system when the current in the disturbing circuit remains fixed. It is usually more convenient to employ a shield factor (η) in actual calculations. This may be defined as the ratio of the resultant voltage in the disturbed circuit, after introduction of a shielding system, to the nonshielded induced voltage, each resulting from the same current in the disturbing circuit. The effective coupling between the disturbing and disturbed circuits in the presence of a shielding circuit is equal to the mutual impedance between the circuits in the absence of the shielding circuit multiplied by the shield factor. A low shield factor represents a desirable condition, since it indicates a large reduction of voltage.

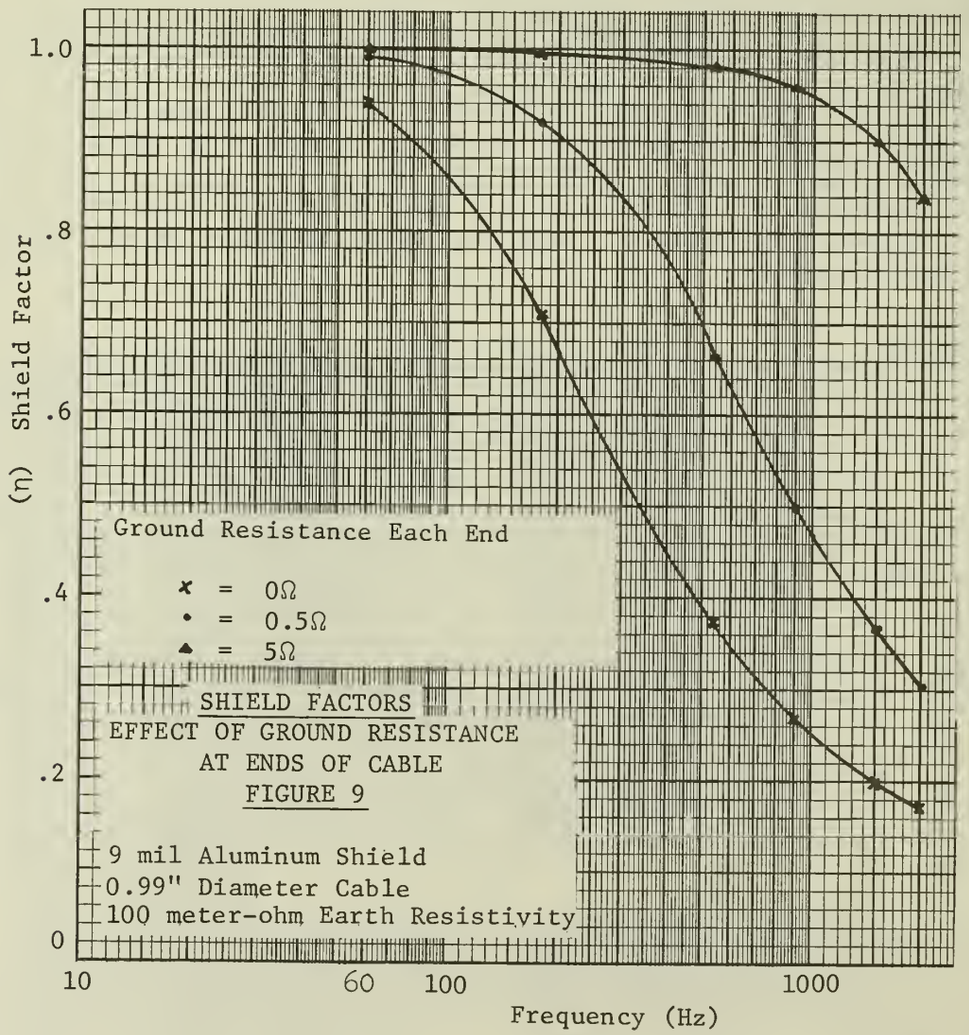
5.231 A shielding circuit is most effective when the total resistance including both the shield conductor resistance and the resistance to earth of the ground connections is small, if either part of the total shield circuit is fixed, there is a practical limit beyond which it is uneconomical, based on the results obtained, to further lower the variable resistance.

5.232 Earth resistivity, resistance to earth of ground connections, resistance of shield conductor, frequency and total length of shielding circuit all have a bearing on the shield factor. Figures 8 through 14, inclusive have been included to illustrate these relationships. Derivation of these figures will be discussed in detail in TE&CM Section 452.

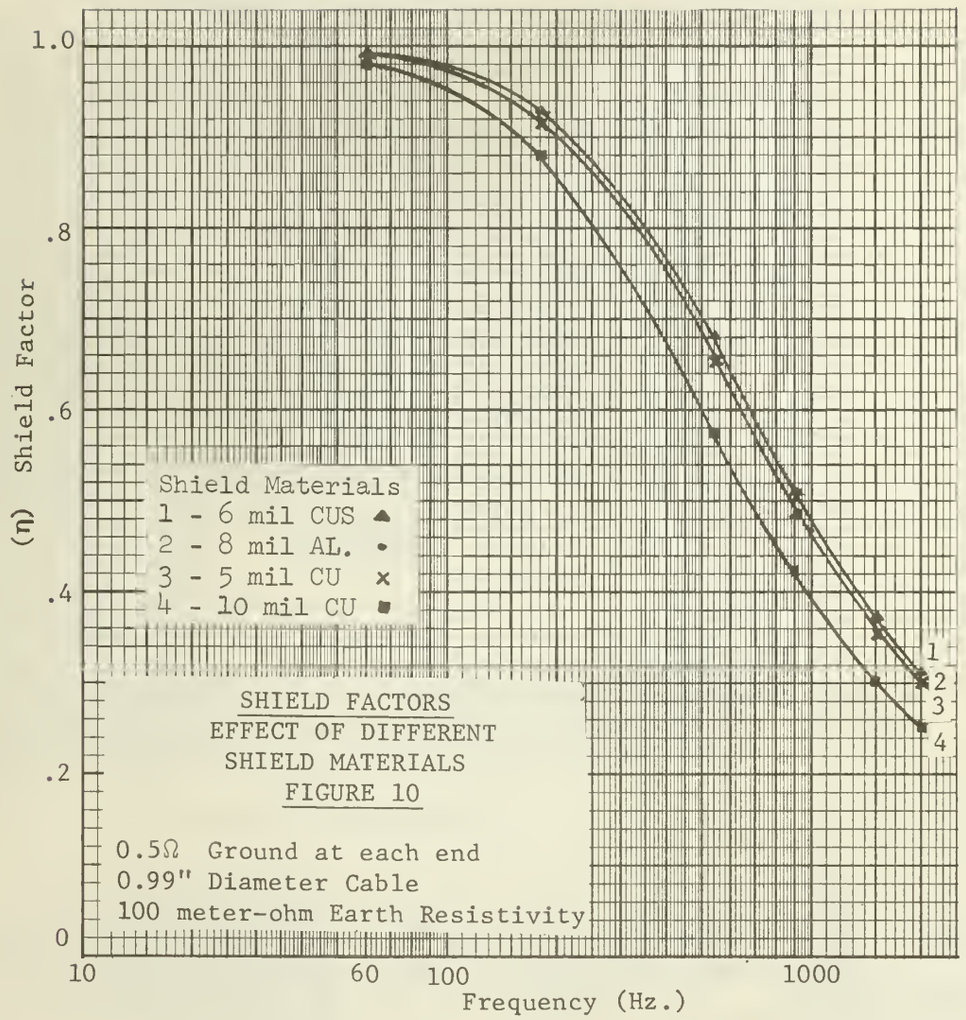
5.233 Variation of shield factor (η) with variations in earth resistivity is shown in Figure 8. Note that there is almost no shielding at the fundamental frequency.



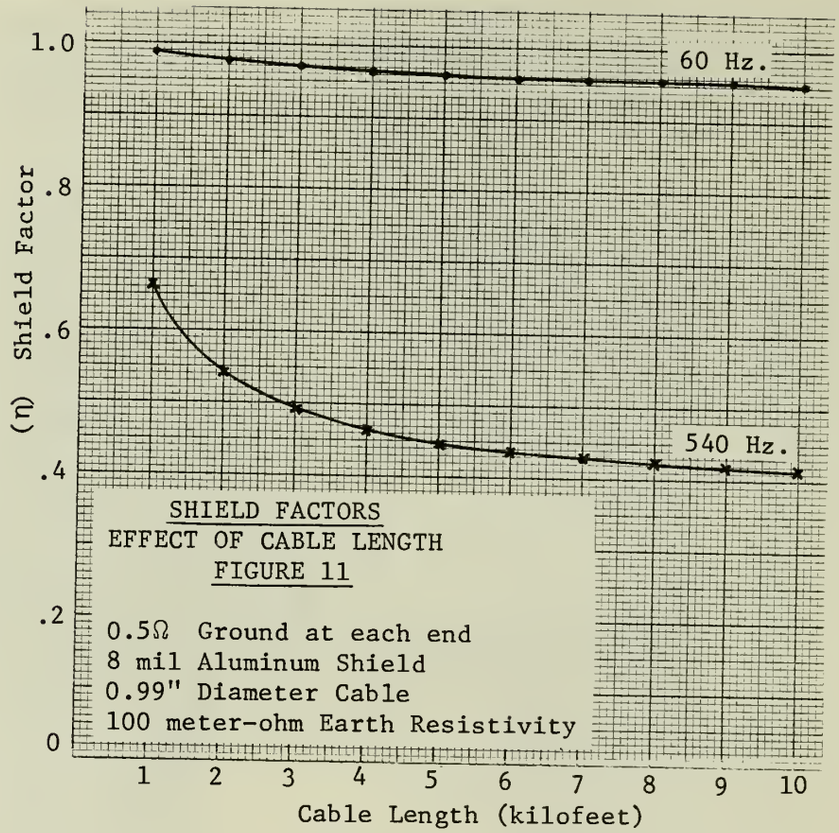
5.234 Figure 9 illustrates the variations in shield factor associated with varying values of resistance to earth for grounded end connections with a circuit one kilofoot in length. It will be shown later that where only grounded end connections exist their effect on the shield factor reduces as the circuit becomes longer.



5.235 Variation of shield factor with the various materials commonly used for telephone cable shields is illustrated in Figure 10. Very little improvement can be achieved at the fundamental frequency by substituting 10 mil copper for 6 mil copper steel. At 540 Hertz an improvement of about 16 percent can be attained.



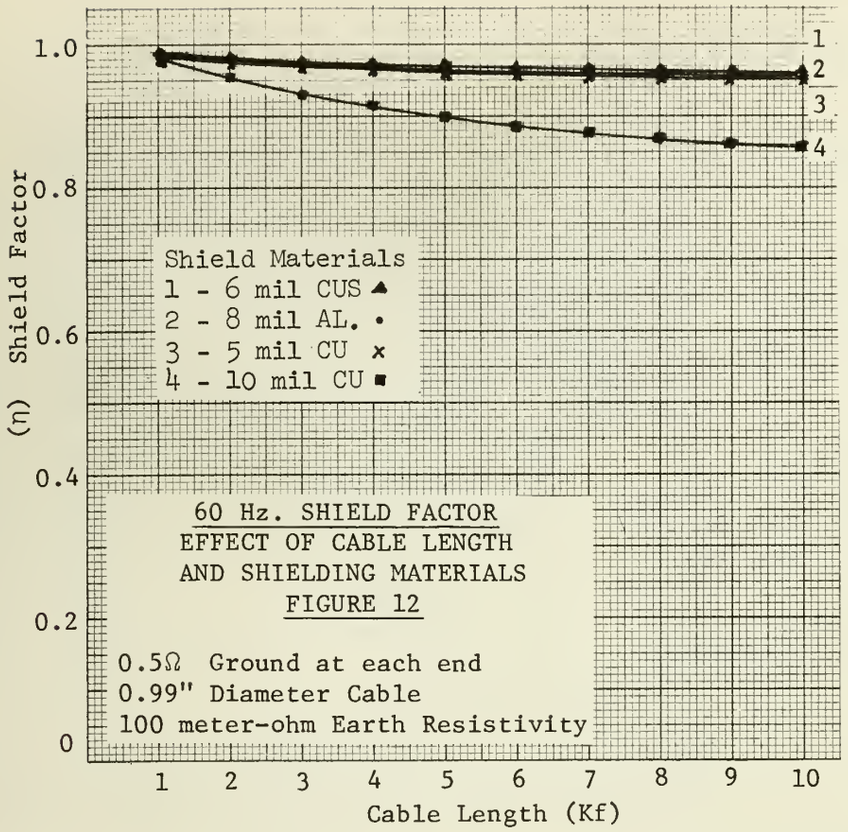
5.236 Figure 11 shows the shield factors for 60 and 540 Hertz with various lengths of cable with an 8 mil aluminum shield and a half ohm ground connection at each end. At 540 Hertz the longitudinal voltage will be reduced to 42 percent of the unshielded magnitude while at 60 Hertz the shielded longitudinal voltage will be 95 percent of the unshielded level. This demonstrates graphically the low shielding efficiency at the fundamental frequency.



5.237 Effects of various shielding materials at 60 and 540 Hertz, respectively, are shown in Figure 12 and 13, for cables of various lengths. Again, the lack of effective shielding at the fundamental frequency is obvious.

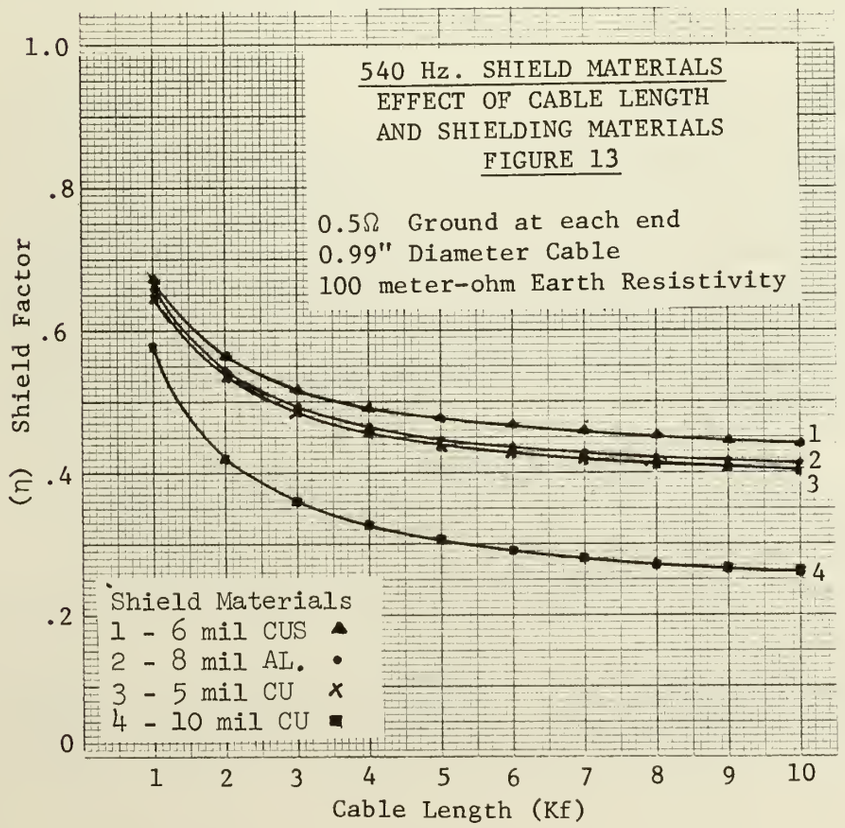
5.238 The differences in shield factor with a ground connection at each end and with intermediate ground connections is illustrated in Figure 14. The condition of only a single ground connection at each end of a cable rarely occurs in actual service. Maximum shielding occurs when there are equal spaced low resistance grounds along the cable shield. This will be discussed in TE&CM Section 451.7.

5.3 It is important that the ground connection and shield resistances be kept as low as practical since the magnitude of the counteracting voltage induced in the cable conductor is the produc of the shield current and the mutual impedance between the cable shield and the cable conductors. If the shield continuity to ground is broken little shield current can flow and there will be no effective shielding. If the ground connection resistance is high, if the shield splice bonds are defective, or if there are high resistance discontinuities in the shield itself, the shielding currents will be reduced and shielding will be less effective. Problems of excessive induced 60 Hertz voltages cannot be corrected by improving the shielding.



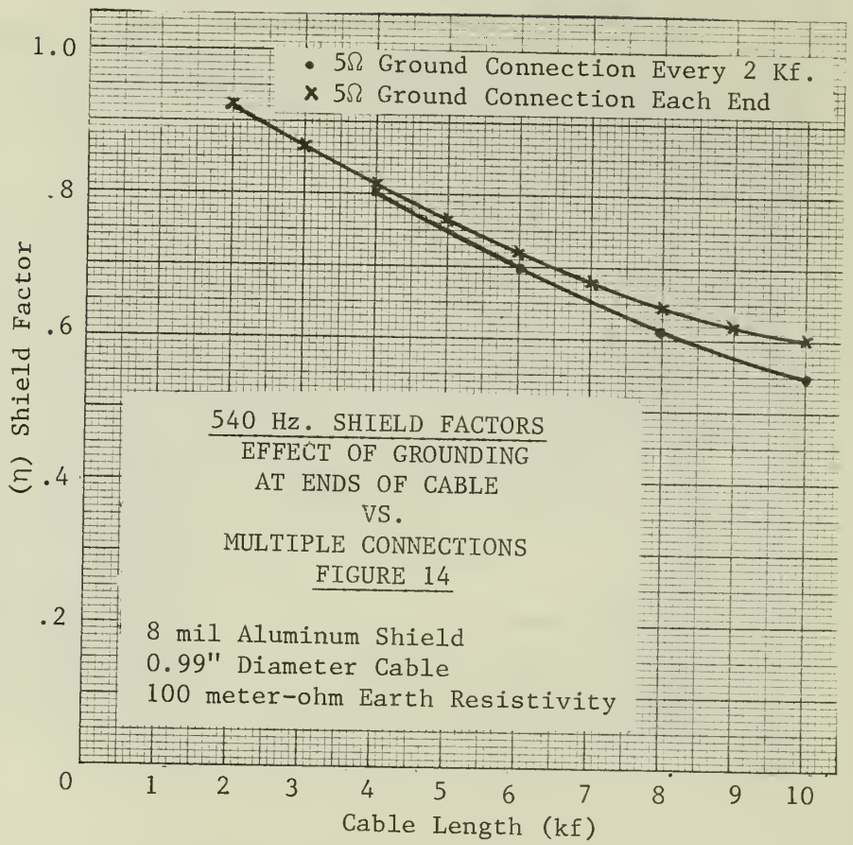
60 Hz. SHIELD FACTOR
EFFECT OF CABLE LENGTH
AND SHIELDING MATERIALS
FIGURE 12

0.5Ω Ground at each end
0.99" Diameter Cable
100 meter-ohm Earth Resistivity



540 Hz. SHIELD MATERIALS
EFFECT OF CABLE LENGTH
AND SHIELDING MATERIALS
FIGURE 13

0.5Ω Ground at each end
0.99" Diameter Cable
100 meter-ohm Earth Resistivity



6. BASIC NOISE FACTORS

6.1 Three factors combine to produce the overall noise on telephone circuits from power induction. They are:

a. Inductive influence of the power system (also called power influence). This is a measure of the interfering effect of the harmonics in the system.

b. Inductive susceptiveness or balance of the telephone system.

c. Inductive coupling between the power and telephone system.

6.2 Characteristics of a power circuit with its associated apparatus (company and subscriber owned) determine the character and intensity of the electric or magnetic field which it sets up in the surrounding medium. These characteristics are termed "Influence Factors". Likewise, characteristics of the telephone line with its associated apparatus determine its responsiveness to external electric or magnetic fields. These characteristics are termed "Susceptiveness Factors". There is also the group of factors which relate to the interrelation of neighboring power and communication lines via electric or magnetic induction or both. These are termed "Coupling Factors".

6.3 Inductive interference is the telephone circuit noise resulting from a combination of influence, susceptiveness and coupling. Inductive coordination is the cooperative engineering approach by both power and telephone representatives for providing satisfactory service to their mtual customers. It consists of the control of the three factors (influence, susceptiveness and coupling) to the degree necessary for satisfactory service performance of both systems. Inductive influence of a power circuit in an exposure is determined by the magnitudes of the harmonic currents and voltages present on the circuit.

6.4 All three basic factors must be present in order for a power induction noise condition to exist. The absence of any one of them would eliminate power induction noise completely. In reality complete elimination is impractical and the ultimate power induction noise will be a function of the basic factor that has the highest influence factor.

7. POWER INFLUENCE

7.1 Power systems in the United States usually operate at a fundamental frequency of 60 Hertz. They also act as generators of harmonic frequencies of the fundamental. At the generator terminals the wave form is a relatively pure sine wave. The basic transmission facilities provide a relatively harmonic free fundamental frequency. If it were possible to maintain a nearly pure voltage and current sine wave throughout a power system, power line induction would be limited to the fundamental frequency with minimum telephone interference. Unfortunately, wave shape distortion can be expected on the power system from two major sources:

1. Nonlinear properties of the power system.
2. Characteristics of the loads from consumer owned devices.

This wave shape distortion produces the fundamental frequency related harmonics present in the current wave form of power systems.

7.2 Power systems from generation plant to customer are a complex network of many types of apparatus. They may be divided into five basic parts: generation, transmission, subtransmission, distribution and customer load.

7.3 The principal types of power systems are three-phase and single phase. Depending on the transformer connection and grounding there are three types of three-phase operation, delta, unigrounded Y, and multigrounded Y. Single phase systems operate with a multigrounded neutral. Configuration of the various systems are shown schematically in Figure 15. Each of these systems has a different potential for power induced interference in the telephone systems.

7.31 Three Phase Delta System: Delta transformer connections are used in some transmission and subtransmission systems. This connection is rarely used in distribution systems. Since there is no neutral wire or ground connection with a delta system the interference potentials are those normally associated with balanced circuits. They are, therefore, dependent upon the balance of current among the three phases and the separation between the power conductors and telephone line.

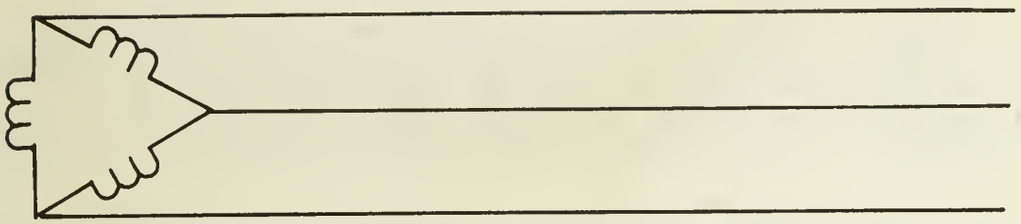
7.311 There are conditions where delta systems can be a source of interference. When long runs of cable parallel high voltage transmission lines the odd triple harmonics (180, 540, etc.) can reach levels in the telephone plant that exceed acceptable limits.

7.312 Under the same parallel conditions described in paragraph 7.311 the induced fundamental frequency longitudinal voltage on the telephone plant can exceed safety limits with only a slight unbalance in the power system. Because of this potential problem long cable runs parallel to high voltage transmission lines should be avoided if at all possible.

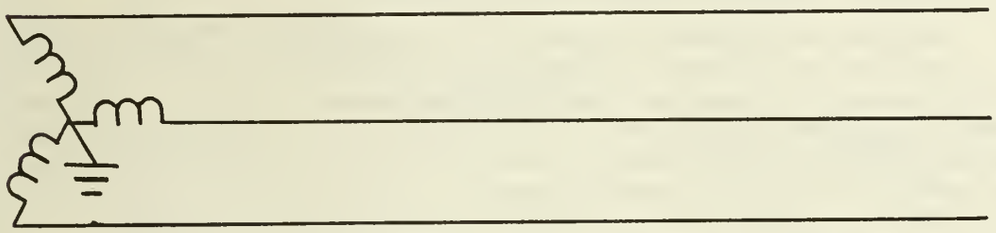
7.313 Another potential problem is the effects on nearby telephone plant when a fault condition occurs along a high voltage transmission line. Very little has been written in REA on this important subject and a discussion of protecting against damage from such fault conditions is beyond the scope of this section.

7.32 Three-Phase Unigrounded Y System: From an interference point of view, at the fundamental frequency, the unigrounded Y system is similar to the delta system providing the above conditions of phase current balance and spatial dependency are satisfied. With the unigrounded Y system there is a neutral conductor providing a current return path but there is only a single ground connection at the originating point. All of the return current is, therefore, forced to return along the neutral conductor in the following manner. When the phase currents at the fundamental frequency are balanced in all three phases, the vector sum of the current in the neutral conductor is zero due to the 120 degree phase relationship.

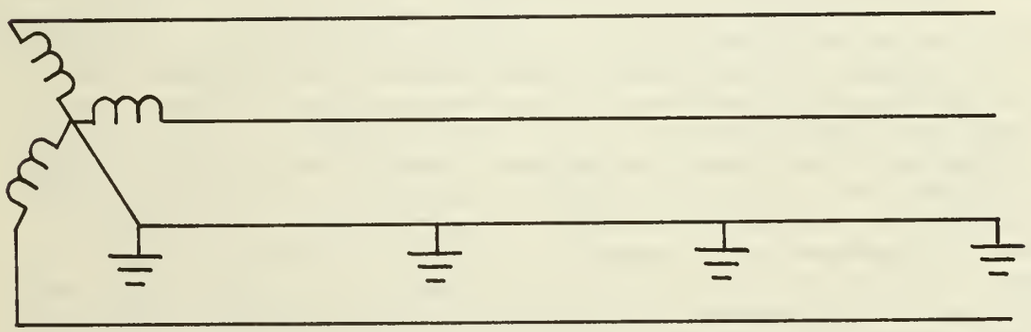
7.321 At 180 Hertz (third harmonic) the maximum value is reached three times as often as the fundamental frequency. Thus when the fundamental has gone 120 degrees, the third harmonic has gone through 3 times 120 or 360 degrees. Therefore, at 180 Hertz, the currents in each phase conductor are in phase and the current in the neutral conductor is the sum of the currents in the phase wires and 180 degrees out of phase.



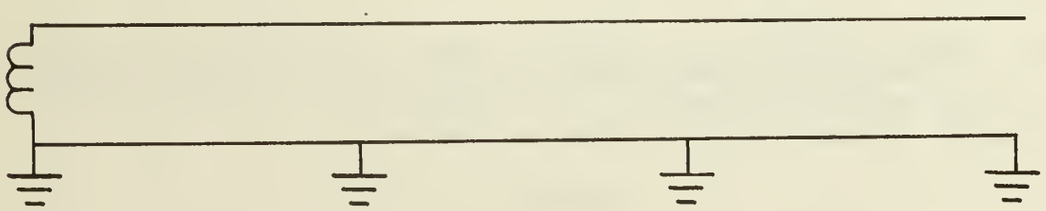
THREE-PHASE DELTA



THREE-PHASE UNIGROUNDED "Y"



THREE-PHASE MULTIGROUNDED "Y"



SINGLE-PHASE MULTIGROUNDED

TYPES OF POWER SYSTEMS

FIGURE 15

7.322 The fifth harmonic (300 Hz.) is 5 times 120 or 600 degrees out of phase. This is equivalent to 600 minus 360 or 240 degrees which corresponds to 120 degrees opposite the fundamental. If the currents in all three phases are equal the algebraic sum of the currents in the neutral conductors will be zero, as for the fundamental frequency. The seventh harmonic is also a balanced component like the fifth.

7.323 In the ninth harmonic (540 Hz.), the phases are 9 times 120 (3 x 360) or 1080 degrees apart and, therefore, in phase. Again, as with the third harmonic, the currents in each phase conductor are in phase and the current in the neutral conductor is the sum of the currents in the phase wires and 180 degrees out of phase.

7.324 Analysis of harmonic currents in a three-phase Y system reveals that all odd harmonic numbers which are divisible by 3 (3, 9, 15, etc.) are in phase in each of the phase conductors. Thus, the current in the neutral conductor is the sum of the currents in the phase wires and 180 degrees out of phase. These harmonics are often referred to as odd-triple harmonics (all odd-integers times 3). Odd harmonics which are not divisible by 3 (5, 7, 11, etc.) are either 120 or 240 degrees out of phase and act like balanced components. These harmonics have no effects on induction in balanced three-phase systems.

7.33 Three-Phase Multigrounded Y System: Three-phase multigrounded neutral (MGN) systems are the most commonly used for power distribution in the United States. Induction from MGN systems involves both the balanced and unbalanced currents previously discussed. Due to the multiple ground connections in these systems, the alternate path provided by the earth for the flow of current back to the source results in a potential interference problem even though 60 Hertz phase currents are well balanced. Since the odd-triple harmonics are adding in phase and some of the current is returning through the earth, induction at harmonic frequencies is of concern. The division of current between the neutral and earth-return circuits is dependent on the characteristics of the particular power system and its associated grounds. This would include but not be limited to the size of the neutral conductor and the earth resistivity in the area of the system. It is not unusual to find 60 percent or more of the current returning in the earth path and 40 percent or less in the neutral wire.

7.331 When the fundamental frequency current flowing in each phase of a three-phase system is equal to the others no 60 Hertz current will flow in the neutral conductor. The entire return current will flow in the other two phase wires as shown in Example 1.

EXAMPLE 1

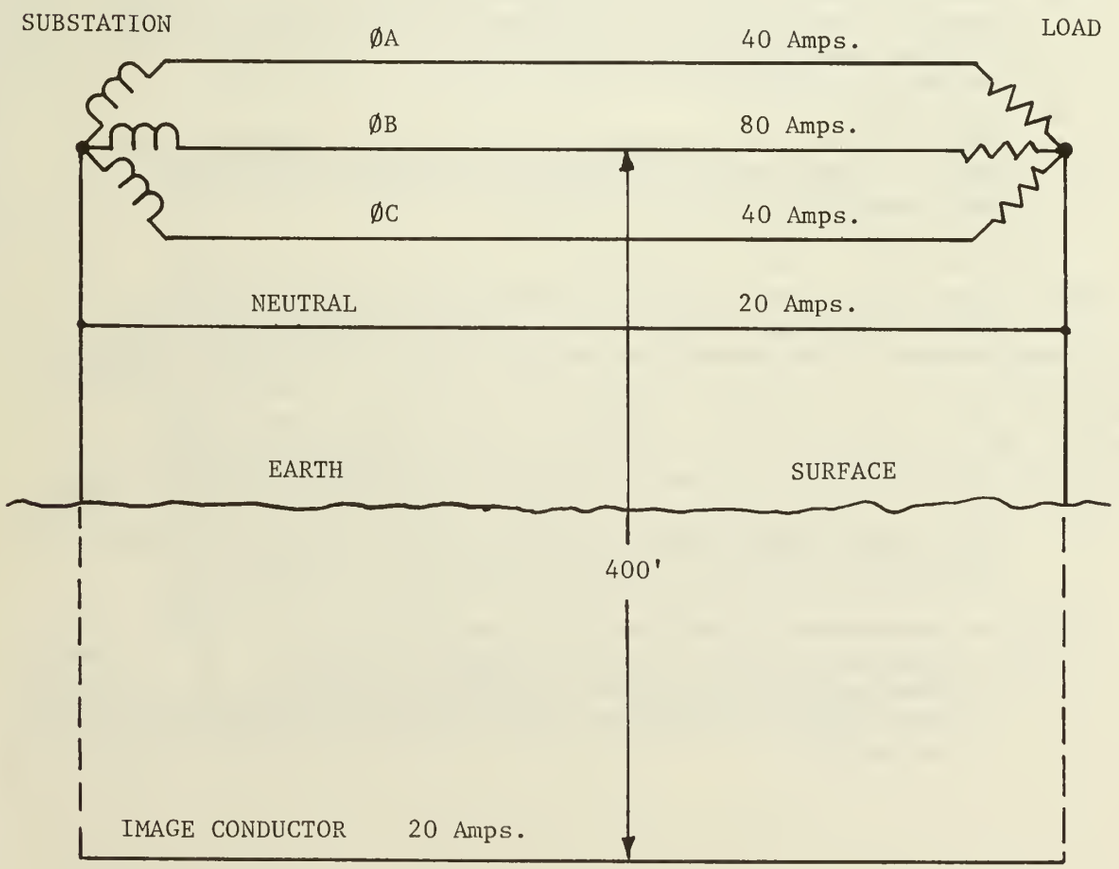
CONDUCTOR	CURRENT IN AMPERES
Phase A	40
Phase B	40
Phase C	40
Neutral	0
Ground	0

Under these conditions the magnetic field produced that would affect the telephone system would be small because each phase wire is close to the others so the magnetic fields cancel and there is no ground return current. It is not the current that flows along one phase wire and returns over the other phase wires that produces the magnetic field which has the greatest effect on telephone cable conductors.

7.332 The current that produces the magnetic field most seriously affecting cable conductors is the unbalance current between the three phases. This current is forced to return to the substation over the power neutral conductor and its associated earth path. (See Figure 16). Example 2 illustrates the relationship when phase to phase unbalance is present in the power system.

EXAMPLE 2

CONDUCTOR	CURRENT IN AMPERES
Phase A	40
Phase B	80
Phase C	40
Neutral	20
Ground	20



GROUND RETURN CURRENT
FIGURE 16

The magnetic field produced under these conditions, that would affect the telephone system, would be much greater than in Example 1. This occurs because the conductors of Phases A, B, C and the neutral are in close proximity to each other (approximately two foot separation) and their magnetic fields ap proximately cancel. The 20 amperes of ground return current, however, is returning to the substation about 400 feet below the earth. This provides very little cancelling effect on the magnetic field produced by the associated 20 amperes flowing in Phase B.

7.4 Single-Phase Multigrounded System: The conditions with single-phas e multigrounded neutral systems is quite different. Harmonic cancellation which occurs in three-phase systems is absent. Thus, all harmonic currents, including the fundamental frequency, divide between the earth and neutral wire paths. This produces a potential for difficult interference problems. Two-Phase multigrounded systems are also unbalanced due to absence of the third phase.

7.5 Power System Harmonic Sources: A power system supplies 60 Hertz power to power users but it can also be a generator of harmonic frequencies. These harmonic frequencies, which are multiples of the fundamental frequency can originate from the following sources:

a. Distribution Transformers and Regulators
b. Power Factor Correction Capacitors (These do not themselves generate the harmonics. See Paragraph 7.521 for discussion of power line capacitor installations).
c. Rotating Machinery
d. Rectifiers
e. High Voltage DC Transmission Lines (Harmonics are generated in the rectifiers and inverters at each end of the line. See Paragraph 7.7).
f. Solid State Power Control Devices

7.51 Distribution Transformers: Distribution transformers are a source of harmonics due to the nonlinear characteristics of the core materials. Increasing the primary voltage to 10 percent above the rated value can increase inductive noise due to harmonic current output by 200 to 300 percent. Even when transformers are not over excited there is always some distortion of the fundamental wave shape but this is usually at a low level so that noise objectives can be met.

7.52 Power Factor Correction Capacitors: Power companies widely use capacitor banks for several reasons, which include:

a. Increasing voltage levels at loads.
b. Raising the power factor at inductive loads
c. Reducing the current and associated I^2R losses
d. Reducing circuit loading, making possible the addition of loads.

7.521 Distribution capacitor banks, unlike transformers, should not be suspected of generating harmonics. However, the flow of harmonic currents generated by other sources may be significantly altered by the presence of capacitors on the power system.

7.522 Sometimes the installation of a capacitor bank will result in a circuit approaching series resonance in the voice frequency pass band. When this occurs, there will be a low impedance to ground at those particular frequencies. Thus, a relatively low harmonic voltage can produce a comparatively high current in the power conductors. This can result in inductive interference in nearby telephone circuits.

7.6 Rotating Machinery: Deviations from perfection in the design and manufacture of generators can cause them to act as producers of harmonic frequencies. The wave shape of generators is one factor in the general problem of inductive coordination between power and communication circuits, but not a major one. Effective control of the wave shape of generators has been accomplished by cooperative efforts among manufacturers, power companies and telephone companies.

7.7 Rectifiers and Inverters: Harmonics appear on the dc side of a rectifier and on the ac side of an inverter. On the dc side of a rectifier the orders of the harmonics are even orders. On the ac side of an inverter there are two harmonics for each one on the dc side with orders of one less and one more than on the dc side. In a six phase line the fifth and seventh, eleventh and thirteenth, etc., are present on the ac side, with the sixth, twelfth, etc., on the dc side.

7.8 Solid State Power Control Devices: These customer owned devices are used for light, temperature, and heat control. Industrial applications include motor drive control and electric furnace control.

7.81 These devices are wired to function as fast action switches. Control of the load is accomplished by changing the proportion of the time that the load is energized. There are two basic ways loads are controlled by these devices, phase or "chopper-type" control and synchronous control.

7.811 Phase or "Chopper-Type" Control: This type connects the ac supply to the load during a fraction of each half Hertz of the supply's sinusoidal wave shape. Control is accomplished by governing the time in each half Hertz that the device allows conduction.

7.812 Synchronous Control: This type switches the load "on" at the instant the sinusoidal supply voltage is zero and then allows conduction for one or more complete Hertz of the supply voltage wave. Control is accomplished by governing the lengths of time "on" and "off". Synchronous control can be used only for resistive loads such as electrical space heating.

7.82 The constant switching on or "chopping" action of phase controlled devices causes harmonic distortion of the power system wave shape. The harmonic frequency spectrum of this distortion is so broad that effective filtering is difficult. Synchronous control avoids the distortion due to chopping.

7.83 Probability of inductive interference increases with the size of the controlled load. Loads of 10 kW or larger are likely to cause trouble in nearby communications circuits even though located near the substation. Loads as small as 3 kW may also cause telephone noise when they are at locations far from the substation.

8. SUSCEPTIBILITY

8.1 Susceptibility can be defined as those characteristics in the telephone system that determine the level of service impairment from a given longitudinal influence. They are usually expressed as the relationship between longitudinal voltage (and/or current) and metallic voltage (and/or current) that results from a given longitudinal influence.

8.2 Significant longitudinal impedance characteristics of a voice frequency subscriber loop are a relatively low impedance to ground at the central office end and a relatively high impedance to ground at the subscriber end. A longitudinal voltage induced on such a circuit will produce a significant voltage to ground at the subscriber end which will diminish to minimum value at the central office end as shown in Figure 17. Conversely, there is minimum longitudinal current flow to ground at the subscriber end and maximum at the central office.

8.3 A useful measure of the ability of the telephone system to prevent longitudinal/metallic conversion of voltages and currents is its overall degree of balance. This may be defined as:

$$\text{Circuit Balance (dB)} = 20 \log \frac{V_L}{V_M} \text{ or } PI - Nm$$

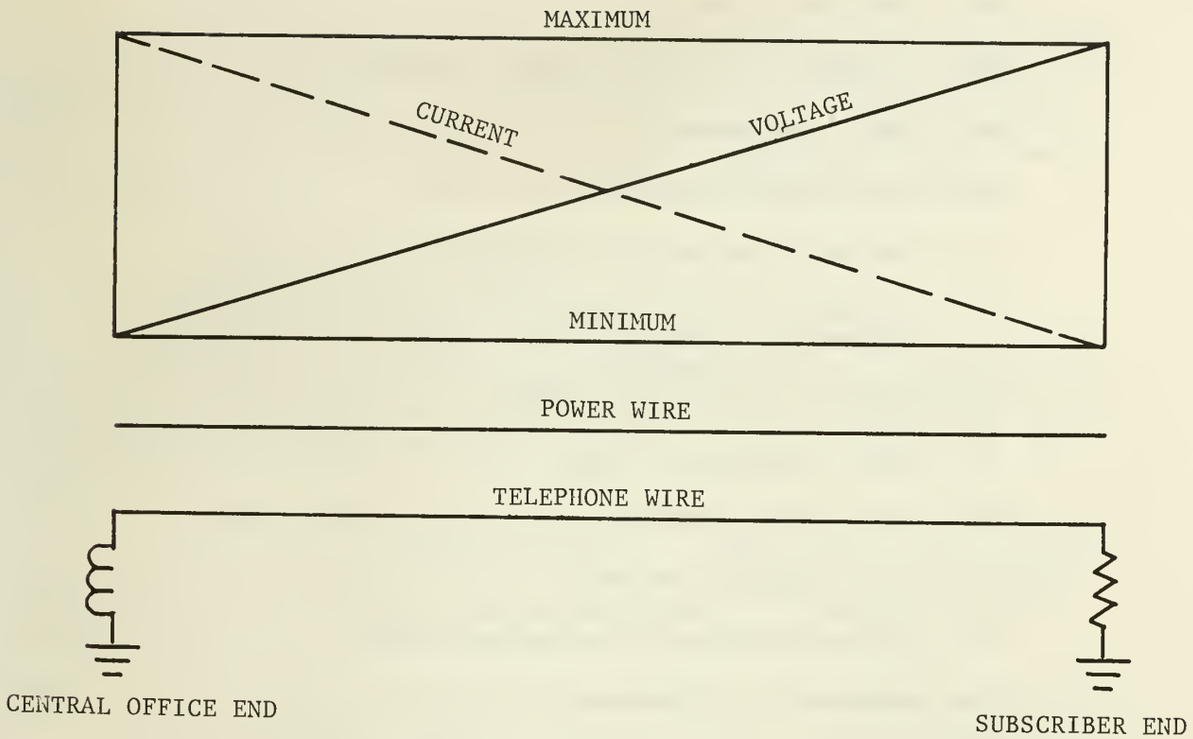
Where:

V_L is the average voltage-to-ground, at a particular frequency, measured on both conductors at the subscriber end of the system, with the CO end grounded.

V_M is the metallic voltage between the two conductors measured at the subscriber end of the system.

PI is the power influence, in dBrnc, measured at the subscriber end of the system.

Nm is the metallic noise, in dBrnc, measured at the subscriber end of the system.



DISTRIBUTION
LONGITUDINAL NOISE VOLTAGE AND CURRENT
SUBSCRIBER LOOP

FIGURE 17

8.31 Elements in the telephone system that can be important factors in system balance are shown below:

8.311 Impedance

(a) Central Office Equipment Battery Feed Relay Windings, including the line circuit, connector circuit, electronic loop extender, long line adapter, etc.

(b) Drainage Units (where used)

(c) Telephone Set Ringers

(d) Some types of ANI (Automatic Number Identification) equipment station connections

8.312 Series Resistance

(a) Conductor Resistance

(b) Loading Coil or BTI (Bridged Tap Isolator)

(c) Splice Resistance

(d) Heat Coil Resistance (Where Used)

(e) Station Protector Fuse Resistance (Where Used)

(f) Carrier Filter Resistance (Where carrier is super imposed on voice frequency loops)

8.313 Resistance-to-Ground (Admittance)

(a) Cable insulation leakage

(b) Glass insulator leakage (open wire plant)

(c) Central Office Protectors

(d) Protector leakage (Station and other)

(e) Terminal block leakage

(f) High voltage protection device leakage

(g) Drainage unit leakage (Where Used)

(h) Cable capacitance unbalance to shield

8.32 In a perfectly balanced telephone circuit, longitudinal induced voltage will cause an equal flow of current to ground from each conductor. As a result, net metallic voltage from induction will be zero. For this to occur a circuit would have to meet the following requirements:

(a) The series impedances of both sides of the circuit are equal.

(b) The admittances of both sides to shield are equal.

(c) The impedances between both sides and any other telephone circuit in the same cable are equal.

8.4 In practical situations all three factors are present, each in differing magnitudes. There is always unbalance in the telephone system, influence from the power system and coupling between the two.

9. NOISE REFERENCE STANDARD

9.1 The objective in telephone circuit noise measurements is to characterize quantitatively the effects of noise on the listener such that two noises that are judged equally interfering are assigned the same numerical magnitude. To accomplish this, the noise measuring set (NMS) weighs the components of a given noise voltage in proportion to their interfering effect, adds the weighted components on a rss (power) basis, and indicates the result on a meter with suitable dynamic characteristics.

9.11 Noise Reference Level (dBrn)

9.12 The reference level for transmission measurements is one (1) milliwatt (10^{-3} watts) and is designated 0dBm. The reference voltage is dependent on the impedance into which the one milliwatt is dissipated. For example, the reference voltage for 0dBm into 600 ohms is 0.775 volts and into 900 ohms is 0.949 volts.

9.13 The reference level for noise measurements is one (1) picowatt (10^{-12} watts) of 1000 Hertz power. This is also 10^{-9} milliwatt (-90 dBm) and is designated 0dBrn. A letter or number following dBrn refers to the weighting at which the measurement is made (eg. 25 dBrnc, 30 dBrn 3 kHz refers to "C" message or 3 kHz flat weighting).

9.14 At 1000 Hertz -90 dBm represents 0dBrn. Zero dBm would, therefore, represent 90 dBrn. Minus 33 dBm at 1000 Hertz would be the same at 57 dBrn (90 - 33 = 57) on a NMS, -69 dBm would be 21 dBrn, etc.

9.15 The reference point for 0dBrn on a NMS is the same for all weightings at 1000 Hertz. However, the reference voltage is dependent on the input impedance as shown in Table II.

TABLE II

VOLTAGE REFERENCE POINTS

NMS SETTING	VOLTAGE AT 1000 HZ. FOR 0dBrn
Ng (Noise-to-ground)	2.45 millivolts to ground--10^{-5} milliwatts into 600 ohms
BRDG	24.5 microvolts--10^{-9} milliwatts into 600 ohms
600	24.5 microvolts--10^{-9} milliwatts into 600 ohms
900	30.0 microvolts--10^{-9} milliwatts into 900 ohms

9.2 Frequency Weighting

9.21 Noise measuring sets incorporate C-Message Weighting which provides a standard characteristic for the measurement of telephone circuit noise. This is the present standard for exchange noise work. The sets also provide networks for measuring on program and special service circuits.

9.22 C-Message Weighting

The frequency characteristics of the C-Message Weighting are shown in Figure 18. This network, which is used for measurement of noise on message circuits, is very important since if reflects the amount of noise a subscriber actually hears. C-Message Weighting characteristics were determined by subjective tests and include the frequency response of a Western Electric 500 or equivalent type telephone set and hearing mechanism. Thus, use of C-Message Weighting in the measuring instrument provides a means of making an objective measurement to characterize a subjective response.

9.23 3 KHz Flat Weighting

The response of 3 KHz flat weighting is also given in Figure 18. This weighting removes nearly all attenuation in the range of 60 Hertz to 3 KHz, which is present in C-Message Weighting. Normally this measurement provides the level of the fundamental frequency (60 Hz.) only. This is on the assumption that the level of 60 Hertz is substantially higher than the harmonics and thus the presence of the harmonics does not substantially increase the 3 KHz flat reading. This weighting is normally used during noise investigations to determine the magnitude of fundamental frequency voltage.

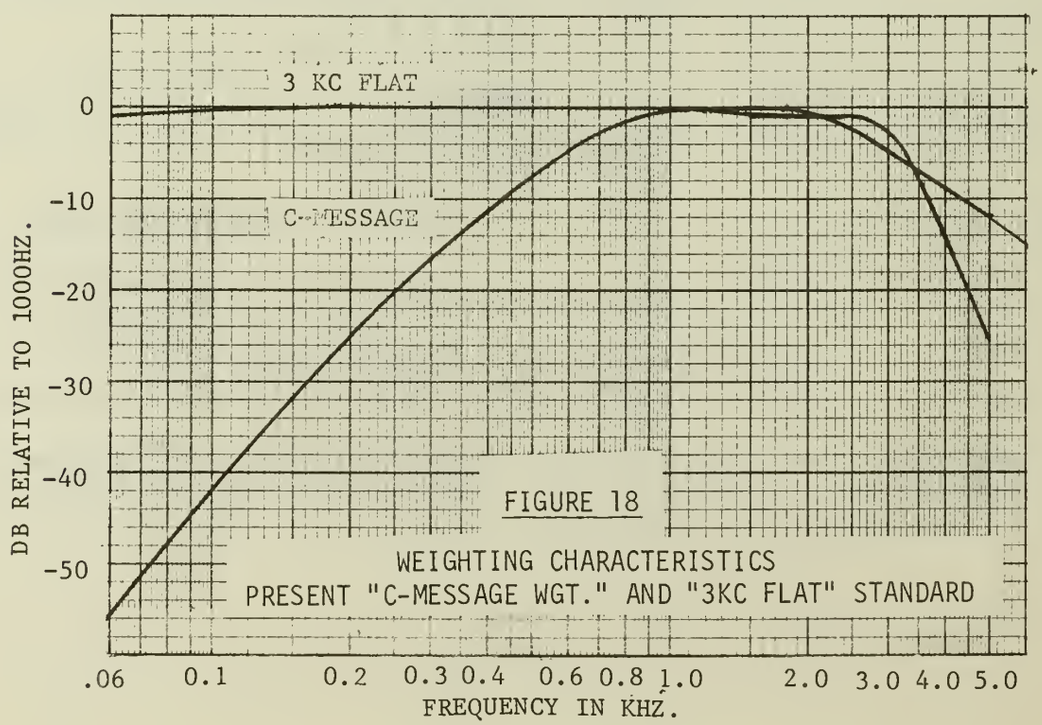


FIGURE 18

WEIGHTING CHARACTERISTICS
PRESENT "C-MESSAGE WGT." AND "3KC FLAT" STANDARD

9.24 Program Weighting

Program weighting is used for measurements of noise on program circuits with bandwidths up to about 8000 Hertz. Program weighting differs from message weighting in that the design of the weighting network takes into account the response of the program receiving equipment rather than the response of the telephone instrument.

9.25 15 KHz Flat Weighting

The 15 KHz flat weighting is used to measure noise on studio to transmitter program loops and on wired-music circuits. These circuits require flatter and wider bandwidths than regular program circuits.

10. COORDINATION

10.1 Line facilities of power and telephone systems are usually closely associated. Thus, problems of electrical interference can be created. The control of such interference involves the design, maintenance, and operating practices of both systems as well as the relative locations of both lines. In situations where standard designs and procedures will not prevent interference or keep it at a tolerable level, modifications on the part of one or both systems may be necessary. This will usually require coordinated engineering efforts for the best overall solution.

10.2 In 1945 the Joint General Committee of the Edison Electric Institute and the Bell System reissued three earlier reports covering the cooperative handling of electrical coordination problems. Two important points in these guides are:

(a) To meet public service needs, the solution of inductive interference problems in a mutual responsibility of the power and telephone companies.

(b) Carrying out this responsibility in an equitable and economical manner requires the establishment of cooperative arrangements between the utilities.

10.3 Many Public Utility Regulatory Commissions have issued orders concerning inductive coordination. These orders which <u>have not been issued by all regulatory commissions</u> and which <u>vary considerably</u> should be reviewed for each location involved. For the most part, such regulations specify the following:

(a) Cooperation to prevent or mitigate inductive interference problems.

(b) Advance notice of new construction, rearrangements or changes in operating procedures which cause inductive interference.

(c) Application of the principle of the least total cost in situations where there are several methods for mitigating or preventing inductive interference.

(d) Referral to the regulatory agency if parties cannot agree on a procedure for mitigating or preventing inductive interference.

10.4 Handling of Inductive Coordination Problems

Considerations toward developing improved relations between power and telephone companies include the following:

(a) A consistent method must be followed during investigation of noise problems to insure that the telephone company has a problem requiring power company assistance before any contact is made.

(b) Contacts with the other company should be made through designated personnel.

(c) All requests whether for information, participation or action should be followed up with written correspondence.

(d) Should action by the power company seem necessary to solve an interference problem, that company should be invited to participate in determining a proper solution rather than unilaterally proposing one.

(e) Persons designated as contacts with the power companies should know and understand the other company representatives point of view and be able to adequately present their own companies point of view.

(f) Supervisory persons from both companies should know each other and meet periodically to discuss matters of mutual concern.

(g) Requests and correspondence from the power company should receive prompt attention. All commitments must be met to avoid delays in construction or rearrangement work that requires coordination of forces from both organizations.

10.5 Most regulatory commissions require some form of cooperation between power and telephone companies and in varying degrees designate how it is to be carried out. Mutual cooperative effort could preclude additional regulations that might be less desirable and less flexible for all.

10.6 Principles for Inductive Coordination

The general principles for inductive coordination that follow are given as a guide for establishing satisfactory relations between power and telephone companies.

10.61 Mutual Responsibility: Power and telephone companies are public utilities supplying essential public services. There is a mutual responsibility to cooperate in preventing and mitigating interference in the services provided.

10.62 Cooperation: Each company should notify the other in advance of planned construction or changes in operating conditions which might require inductive coordination.

10.63 Coordination Methods: These methods should include, as far as practical, limiting the inductive influence of the power facility, the susceptibility of the telephone facilities, and the coupling between them. Where such methods prove inadequate, specific coordination methods should be applied to facilities of either or both to reduce interference to an acceptable level.

10.64 Coordinated Locations for Facilities: Joint utilization of highways, rights-of-way, trenches and structures is usually the most economical and efficient way of extending and maintaining power and telephone facilities. Planning of major facilities should be coordinated to keep inductive exposure to a minimum.

10.65 Specific Coordination Methods: Where specific coordination methods are required, the best engineering solution should be adopted by applying the following principles:

(a) Specific methods should meet the service requirements of both systems in the most convenient and economical manner without regard to whether they apply to power or telephone systems or both.

(b) All factors should be considered for all facilities involved. These include both current factors and those that might be required for foreseeable future conditions.

(c) In determining specific methods to be adopted, neither company should judge the service requirements of the other system, or what constitutes good practice in that system.

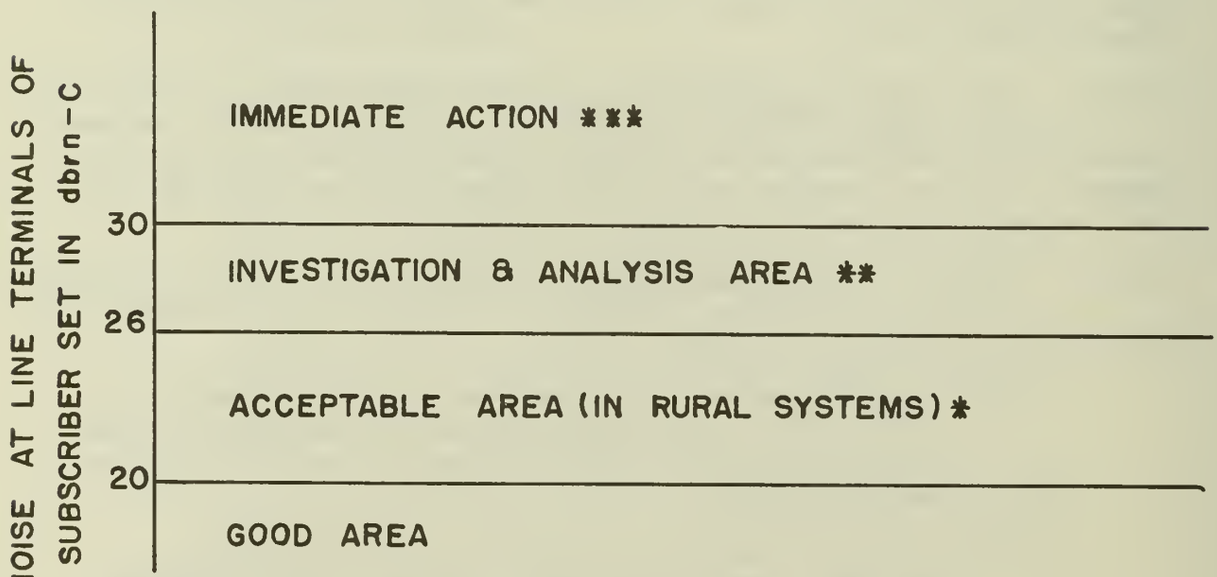
10.66 Deferred Coordination: Conformance to general coordination methods might be deferred, if economically advantageous, on existing or new facilities of one company when such facilities are alone. Conformance should be applied when development of facilities by the other

company creates a problem. Where existing facilities of either company do not conform to general coordination methods, conformance should be applied upon identification of the need by either party.

11. NOISE OBJECTIVES

11.1 Provision of high quality telephone service dictates that subscribers receive more and better services as the technological state of the art permits. This includes, of course, better transmission and quieter circuits. For this reason both transmission and noise objectives are always under study and subject to reevaluation and improvement. Current REA noise objectives for subscriber loops and trunk for steady state noise are given in REA TE&CM Section 415.

11.2 Figure 19 gives the noise maintenance limits for steady state noise for subscriber loops. The acceptable, marginal, investigation and analysis, and immediate action areas are clearly shown.



*Marginal in Urban Areas

**Marginal in all areas

***Cause for concern. Corrective action should be taken.

SUBSCRIBER LOOP NOISE MAINTENANCE LIMITS

FIGURE 19

11.3 Measurements for establishing the magnitude of and isolation of circuit noise are shown in TE&CM 451.1. Procedures for investigation of noise problems are discussed in Paragraph 12 & 13.

12. INTERPRETATION OF NOISE MEASUREMENT DATA

12.1 As indicated previously in Paragraph 9, noise measurements are made in dBrnc which assigns a quantitative value to the noise on a telephone line, giving a different weight to each frequency component (harmonics of 60 Hertz). C-message weighting is the present standard for noise work in the United States. The two most frequently used measurements of dBrnc are circuit noise (metallic) and power influence. Circuit noise is that across the metallic pair and is the noise heard by the subscriber. Power influence measurement in effect connects the two wires of the metallic pair together and measures the dBrnc to ground.

12.11 All noise measuring sets measure the voltage-to-ground in the same manner via a voltage divider which attenuates the signal 40 dB. Some sets have a scale calibration which requires adding 40dB to the reading to obtain the actual value of the level measured. Scales of other sets are calibrated so this 40dB attenuation has been taken into account and the actual level can be read directly without adding the 40 dB. Since balance should be derived from the value which includes the 40 dB correction care must be taken to know the scale calibration for the noise measuring set being used.

12.12 The terms Noise-to-Ground (Ng) and Power Influence (PI) have usually been considered synonomous when making measurements regardless of the type set used. Some confusion can be avoided by applying the term Noise-to-Ground to readings obtained when using sets requiring the addition of 40 dB and Power Influence when using sets which do not require the addition. When thought of in this manner Noise-to-Ground may be converted to Power Influence, which is used to calculate balance, by adding 40 dB (PI = NL + 40).

12.13 A third measurement is called Noise Longitudinal. This measurement can be made only with the isolation or termination set of the type shown in TE & CM Section 451.1. It is the measurement of noise in dBrnc across a resistor in the longitudinal path of a center tapped coil. The short circuited tip and ring conductors are connected to the center tap of the coil through the resistor. This resistor has a value of 1/100 the impedance of the noise measuring set. Thus, it is necessary to add 40dB to the results of this measurement to derive the Power Influence (PI=NL + 40).

12.131 This method is valuable when measuring in the vicinity of a low impendance to ground such as near the central office. Longitudinal current and voltage levels along a subscriber loop are discussed in paragraph 8. From this it can be seen that at some point along the cable measured volue of Noise Longitudinal will be the same as that of Noise-to-Ground. At the subscriber location the Noise-to-Ground will be much higher than Noise Longitudinal while near the office the reverse will be true.

12.132 Even though 40 dB is added to both Ng and NL to obtain PI it cannot be stated that Ng = NL for one is a measurement of longitudinal voltage to ground and the other is a measurement of longitudinal current flow. Both measurements should be made at each location and the highest value used to calculate balance.

12.2 Subscriber tolerance to various dBrnc levels varies widely. For a typical subscriber, a line with 20 dBrnc of noise will be rated good or better. It has also been established that loop noise in excess of 30 dBrnc is totally unacceptable and immediate action should be taken to reduce the noise. Values between 20 and 26 dBrnc are considered marginal in urban areas and some action toward improvement is indicated. For long rural oops, 20-26 dBrnc is considered acceptable and 26-30 dBrnc marginal provided it does not result in subscriber complaints.

12.3 Poor telephone circuit balance, high influence from the power system or a combination of both can contribute to subscriber noise. Results of noise measurements can be used to determine circuit balance. This can be used to determine whether telephone system balance or power system influence are controlling. On a subscriber loop, "Noise Metallic" and "Power Influence" are measured at the subscribers location. For trunk circuits, the same measurements are made at the central office(s). Since the measurement at the central office is near a low impedance to ground, "Noise Longitudinal" should be measured and converted to "Power Influence" for computation of balance.

Telephone circuit balance is determined by taking the difference between the measured power influence and noise metallic values in dBrnc. (PI - Nm = dB Balance).

12.31 The accepted method for determining the longitudinal balance of various components in the telephone network is to inject a balanced longitudinal signal on the tip and ring conductors and measure the magnitude of that signal that has been converted to a metallic signal across the tip and ring conductors. The balance in dB is then computed as follows:

$$\text{dB Balance} = 20 \log \frac{V_g}{Vm}$$

Where: V_g = The magnitude of generated signal in volts.

Vm = The magnitude of the metallic signal in volts.

Overall circuit balance in the field may be determined from the results of noise measurements. The longitudinal induced voltage from the power system (Power Influence) is used in lieu of an oscillator derived signal. The dB Balance is equal to Power Influence (PI) less the Circuit Noise (Nm). dB Balance = PI - Nm.

12.32 Circuit balance will be accurate only to the extent that the metallic noise results from the conversion of the longitudinal induction to metallic signals. Should there be other dominant metallic noise sources, such as that originating in the central office battery or carbon transmitter of a station, accurate balance measurements may not be possible. Experience has indicated that, where the power influence is greater than 60 dBrnc and the noise contribution of the carbon transmitter is eliminated through use of passive termination, the metallic noise will generally be the result of longitudinal-to-metallic conversion and accurate balance computations can be made.

12.33 The degree of telephone line balance can be determined from Table III below:

TABLE III

TELEPHONE LINE BALANCE

COMPUTED BALANCE (dB)	(SUSCEPTIVENESS) GRADE OF BALANCE
50 or below	Poor
50 to 60	Marginal
60 to 70	Good
70 and greater	Excellent

12.4 Two other factors are important in the investigation of noise problems. One is the potential of the power system for generating an interference environment and the other is the degree of coupling between the power and telephone lines. A measure of both is indicated by the magnitude of power influence measurements. Unacceptable circuit noise levels can occur with marginal power influence if Telephone line balance is less than excellent. The degree of these factors can be determined from Table IV below:

TABLE IV

POWER LINE INFLUENCE

POWER INFLUENCE IN dBrnc	GRADE OF INFLUENCE
80 or below	Acceptable
80 to 90	Marginal
90 and Over	Unacceptable

12.5 Changes in power load during the day can result in higher power influence levels with a resulting higher and unacceptable circuit noise, even though at the time measurements are made balance is marginal and circuit noise levels are acceptable. Where such conditions are found, it would be advisable to repeat the measurements during the period of peak power demand.

12.6 In addition to the applications discussed in paragraph 12.3 and 12.4 above, "Noise-to-Ground" is also useful for determining the magnitude of low frequency induction. In determining these voltages the "Noise-to-Ground" is measured and converted to power influence as shown in paragraph 12.11. The open circuit voltage may then be found in Table V. When a noise measuring set having 3kHz weighting is not available ac voltage from tip to ground and ring to ground may be measured with a good volt-ohmeter. CAUTION: When measuring voltage to ground in this manner a meter with dc blocking must be used to avoid errors in measurement.

12.7 Preliminary Analysis of Data: Information obtained during preliminary measurements may be used as a broad diagnostic tool. Review of this data may point to a potential trouble source or to indicate the direction subsequent investigation should take. Following is a list of key points which should help determine the course of further work.

(a) Power influence (3 KHz Flat) is greater than 126 dBrn: The 50-volt induced ac guideline is exceeded; (see REA TE&CM Section 825); work with power people to reduce influence. (See paragraph 15)

(b) Power Influence, (C-message) is greater than 90 dBrnc: Circuit noise objectives would be exceeded even with superior plant balance; first, work to reduce coupling by improving telephone plant shielding and, if unsuccessful, to reduce influence of the power system.

(c) Power influence, (C-message) is greater than 80 dBrnc: Circuit noise objectives could be exceeded with good plant balance; work to reduce coupling by improving telephone plant shielding.

(d) Power Influence, (C-message) is less than 80 dBrnc: Circuit noise objectives would not be exceeded with good plant balance, work to improve balance.

(e) Balance, (C-message) is less than 60 dB: Work to improve balance. Apply isolation techniques (see paragraph 13.4) to locate unbalance.

(f) One Kilohertz loss is 3 dB greater than estimated: Work on cable to determine cause of transmission degradation before proceeding further with noise investigation.

(g) DC Loop Current less than 20 mA: Investigate cause prior to continuing noise investigation.

Values shown above are broad guidelines and should not be considered as absolute figures for application to all cases.

TABLE V
CONVERSION CHART
POWER INFLUENCE READINGS (3khz Flat)*
TO OPEN CIRCUIT VOLTAGE

dB	Open Circuit Volts	dB	Open Circuit Volts	dB	Open Circuit Volts	dB	Open Circuit Volts	dB	Open Circuit Volts
90.5	.8207	100.5	2.595	110.5	8.207	120.5	25.95	130.5	82.07
91.0	.8693	101.0	2.749	111.0	8.693	121.0	27.49	131.0	86.93
91.5	.9208	101.5	2.912	111.5	9.208	121.5	29.12	131.5	92.08
92.0	.9754	102.0	3.084	112.0	9.754	122.0	30.84	132.0	97.54
92.5	1.033	102.5	3.267	112.5	10.33	122.5	32.67	132.5	103.3
93.0	1.094	103.0	3.461	113.0	10.94	123.0	34.61	133.0	109.4
93.5	1.159	103.5	3.666	113.5	11.59	123.5	36.66	133.5	115.9
94.0	1.228	104.0	3.883	114.0	12.28	124.0	38.83	134.0	122.8
94.5	1.301	104.5	4.113	114.5	13.01	124.5	41.13	134.5	130.1
95.0	1.378	105.0	4.357	115.0	13.78	125.0	43.57	135.0	137.8
95.5	1.459	105.5	4.615	115.5	14.59	125.5	46.15	135.5	145.9
96.0	1.546	106.0	4.888	116.0	15.46	126.0	48.83	136.0	154.6
96.5	1.637	106.5	5.178	116.5	16.37	126.5	51.78	136.5	163.7
97.0	1.734	107.0	5.485	117.0	17.34	127.0	54.85	137.0	173.4
97.5	1.837	107.5	5.810	117.5	18.37	127.5	58.10	137.5	183.7
98.0	1.946	108.0	6.154	118.0	19.46	128.0	61.54	138.0	194.6
98.5	2.061	108.5	6.519	118.5	20.61	128.5	65.19	138.5	206.1
99.0	2.184	109.0	6.905	119.0	21.84	129.0	69.05	139.0	218.4
99.5	2.313	109.5	7.314	119.5	23.13	129.5	73.14	139.5	231.3
100.0	2.450	110.0	7.748	120.0	24.50	130.0	77.48	140.0	245.0

*Power Influence = Noise-To-Ground + 40dB

13. CONTINUATION OF INVESTIGATION

13.1 When results of the preliminary measurements are greater than the levels suggested in paragraph 12.6 alternative investigation procedures should be followed. There is a good possibility that many noise problems can be solved by either reducing the effective coupling by shielding or reducing the susceptiveness by improving the balance of the facility. Experience has shown that where the power influence is less than 80 dBrnc the investigation should concentrate on improving the balance. When the power influence exceeds 80 dBrnc the investigation should first be directed toward determining shield effectiveness and whether shielding might be improved to reduce effective coupling.

13.2 Many noise problems result from combinations of contributing factors at several locations along the telephone circuit. These should be located and corrected individually.

13.3 Methods for determining shield effectiveness are presented in TE&CM Section 451.2. Discussion of test procedures for isolating and locating various types of shielding problems is included. Shielding problems, both open and high resistance connections, have been found to be a major factor during noise investigations.

13.4 Procedures for isolating the source of circuit unbalances are shown in TE&CM Section 451.1. Two methods are discussed, one for use with working circuits and the other for use with idle cable pairs.

13.5 A noise problem may persist even after the coupling has been reduced to its lowest possible level by improving shielding in the telephone system and balance has been improved to the highest possible level. This will usually occur when power influence is in the high range (greater than 90 dBrnc). In such cases, it is helpful to look at the power system in the area to perhaps locate factors contributing to the noise problem. Suggested methods are discussed in TE&CM Section 452, together with data which can be given the power company to support a request for joint coordination.

14. SOURCES OF TELEPHONE SYSTEM UNBALANCE

14.1 When interpretation of data indicates telephone system unbalance is a factor, the following general sources of unbalance should be considered.

14.11 Unbalance in the battery feed circuits in the central office equipment for subscriber or trunk circuits.

14.12 Unbalance in electronic equipment installed in the central office such as voice frequency repeaters, loop extenders, signaling sets, etc.

14.13 Unbalanced cable pairs or open wire lines resulting from series resistance unbalance.

14.14 Unbalanced cable pairs or open wire lines due to shunt unbalance, insulation leakage or capacitance-to-ground unbalance.

14.15 Unbalance due to some types of party line identification methods.

14.16 Unbalance resulting from split cable pairs.

14.17 Unbalance station installations due to wiring errors.

14.18 Unbalance due to divided ringing.

14.19 Unbalance due to foreign attachments.

14.20 Unbalance due to foreign materials in ready access terminals.

14.21 Unbalance due to defective drop wires in aerial cable.

14.2 A checklist of potential noise sources in the various parts of the telephone system is included in Appendix B.

15. MITIGATION

15.01 Mitigation is the last resort in solving noise problems. It is not problem free and usually requires additional expense. Such procedures also change the characteristics of the plant to which applied. Although this is the least desirable means of reducing telephone system noise, it is the most attractive, since it can be applied selectively after a problem has been identified.

15.02 Major risks in elimination of noise problems by this method are:

(a) Creation of a new problem while eliminating another.

(b) Addition of a component to the system that reduces reliability and increases maintenance.

(c) Addition of devices requiring additional personnel training due to the uniqueness of the solution.

(d) Creation of added expense related to administration of potential problems resulting from additional components.

15.03 Noise Mitigation - Telephone

Procedures for minimizing susceptibility of the telephone system will be presented first. These methods should only be considered after all other possibilities have been exhausted.

15.04 Resistance Unbalance: Some noise problems are caused by series unbalances in the metallic pair or central office termination. These problems can sometimes be minimized by making tip and ring reversals along the metallic pair at appropriate location(s) to reduce the series unbalance at critical points.

15.041 This action should be attempted only when it has been established conclusively that the series (resistance) unbalance is a major factor in the noise problem. A simple unbalance measurement of overall resistance unbalance will not always establish this fact.

15.042 As discussed in paragraph 8 the induced voltage on the normal subscriber loop will be highest at the subscriber end and lowest at the central office. Conversely, the current resulting from induced voltage will be lowest at the subscriber end and highest at the office. The longitudinal to metallic conversion due to series unbalance is a function of the longitudinal current. Thus, a relatively high unbalance near the subscriber location may be resulting in minimal noise while a smaller one ear the office will produce high noise.

15.043 It is also possible that a series unbalance near the central office will be offset by unbalance on the other side of the pair in the remainder of the cable. The overall subscriber loop would then have a very small overall series unbalance and yet the major factor contributing to the noise would be the series unbalance.

15.044 Before making tip and ring reversals, the resistance unbalance of the cable should be measured section by section. Loading coil section lengths are convenient for this purpose. Not only is the magnitude of the unbalance important but also the side of the line (tip or ring).

15.045 When points are found where the magnitude of the unbalances are nearly the same in both directions for approximately the same cable length and they are on the same side (tip and ring) reversal should be considered. For example, measuring from a loading point 6 ohms is found in one direction to the next loading point and 5 ohms to the next loading point in the other, both on the ring side. Reversal of tip and ring at the middle load point will result in a one ohm series unbalance between the two outboard load points.

15.046 Where divided ringing is used and tip and ring reversal is made a second one should be made at each subscriber drop connection to insure proper ringing. In lieu of this a second reversal can be made in the main cable before the connection of the subscribers drop.

15.05 Capacitance Unbalance: Many noise problems are the result of shunt unbalances in the metallic pair. These problems can also sometimes be effectively minimized by making tip and ring reversals at appropriate location(s) along the metallic pair to reduce the effective shunt unbalance at critical points.

15.051 This corrective action should only be attempted when it has been established that shunt unbalance is a major vactor in the noise problem. This will usually be determined during noise isolation measurement combined with resistance unbalance measurements. Measurement of the pair capacitance unbalance to shield would be a more precise method of determining whether it is or is not a factor. Equipment for such measurements is quite expensive and the proposed procedure has been proven to produce good results.

15.052 As discussed in paragraph 8 on the normal subscriber loop, induced voltage will be highest at the subscriber end and lowest at the central office. Longitudinal to metallic conversion due to shunt unbalance is a function of the longitudinal voltage. Thus, a relatively high capacitance to shield unbalance near the central office will result in minimal noise while a smaller one near the subscriber will produce significant noise.

15.053 Locating points for tip and ring reversals can be accomplished during noise isolation measurements. When the circuit noise and/or balance is approximately the same in both directions (toward CO and subscriber) a tip and ring reversal can be considered. It is a good practice to verify that the unbalances are both on the same side of the pair (tip or ring) with a capacitance decade. This technique is discussed in TE&CM Section 451.3.

15.054 Where divided ringing is used and a tip and ring reversal is made, a second one should be made at each subscriber drop connection beyond the point of reversal to insure proper ringing. In lieu of this, a second reversal can be made in the main cable before the subscriber drop connection.

15.06 Longitudinal Chokes: As previously stated, some noise problems are caused by series (resistance) unbalances. These may occur either in the wire pair or central office termination. Such problems may be effectively minimized by installing a choke to reduce the longitudinal current. (See TE&CM Section 451.4)

15.061 A longitudinal choke is a two-winding mutually coupled well-balanced transformer. It is connected in series with the tip and ring conductor and poled to present a high longitudinal impedance while only adding the dc resistance of the windings to the metallic circuit.

15.062 Longitudinal chokes should be installed at the central office since they require a current flow for effective operation. They can be quite effective in reducing longitudinal harmonics that fall within the voice frequency band. The effective reduction in longitudinal current is less at lower frequencies. The may also be used at PBX locations and other field locations where there is a low impedance path to ground so enough exciting current will flow.

15.063 Sometimes a resonant condition will occur between the inductor and the capacitance to ground. When this happens the current may increase at some particular frequency.

15.064 Consideration should also be given to the effect of the choke on ringing frequencies. Where divided ringing is used the choke can cause cross-ringing at the higher ringing frequencies. Effects on other transmission characteristics should also be taken into account.

15.065 The high longitudinal impedance presented by the choke can sometimes create a new problem in lieu of the original. The voltage-to-ground will be elevated at the field side of the device. Thus, if there is a high capacitance unbalance to shield existing near the office, it may now become a major factor in continued high level noise on the circuit. Such a condition rarely occurs.

15.07 Neutralizing Transformers: A neutralizing transformer is another form of longitudinal choke. It effectively reduces both longitudinal voltage and longitudinal currents in telephone systems. (See TE&CM Section 451.5)

15.071 Multi winding neutralizing transformers are constructed by winding an ordinary telephone cable on a ferromagnetic core. This cable can be several hundred feet long and the number of pairs, for practical design purposes, range from 6 to 100 pair units.

15.072 Any one pair in the cable may be utilized as a primary winding with all other pairs as secondary windings. In some cases, a separate primary winding is provided to increase the dielectric of the transformer and its efficiency.

15.073 Operation of the neutralizing transformer is similar to the shield discussed in Paragraph 5. The turns ratio of the transformer is one-to-one with a very high self-inductance due to the iron core. Coupling between windings has very low leakage.

15.074 Voltage induced in the secondary windings, as with the cable shield, due to completion of the primary circuit by grounding is a function of the primary current (Ip) times the mutual impedance between the primary winding and the secondary windings. The phase of voltage induced in the cable pairs by the transformer action is in the opposite direction to that induced by the power system. Ideally, complete cancellation would occur, but in practical applications, as with cable shields, it will be incomplete. This is due to internal and external dissipative voltage drops of the primary. These are the dc resistance of the winding, the cable pair resistance which connects to the primary and the grounding resistances.

15.075 Neutralizing transformers haven proven to be effective in reduction of fundamental frequency longitudinal voltage by as much as 90 percent. It is equally as effective in reduction of 60 hertz harmonics provided the harmonic current flows in the primary circuit.

15.0751 When the primary circuit is long and the harmonic frequency is high, it is likely that capacitance-to-ground of cable pair forming the primary circuit would also provide a path for the harmonic current. This would render the transformers less effective in neutralizing those frequencies.

15.0752 Capacitance-to-ground of all the pairs may provide exciting current if no primary pair is available. Performance of the transformer will be slightly degraded in this mode of operation, but it is sometimes used.

15.076 As with any foreign device connected into the telephone system, the neutralizing transformer cannot be used without creating a potential problem. Some of these are discussed below. They should be used discriminately after all factors have been considered.

15.0761 All cable pairs connected through the neutralizing transformer are closely coupled. Thus, a problem on one pair can affect all pairs. For example, a grounded protector on one pair will cause the transformer to reflect a shorted turn which will nullify the neutralization. This will raise the longitudinal voltage on the other pairs.

15.0762 Neutralizing transformers may require lightning protection which might increase maintenance costs.

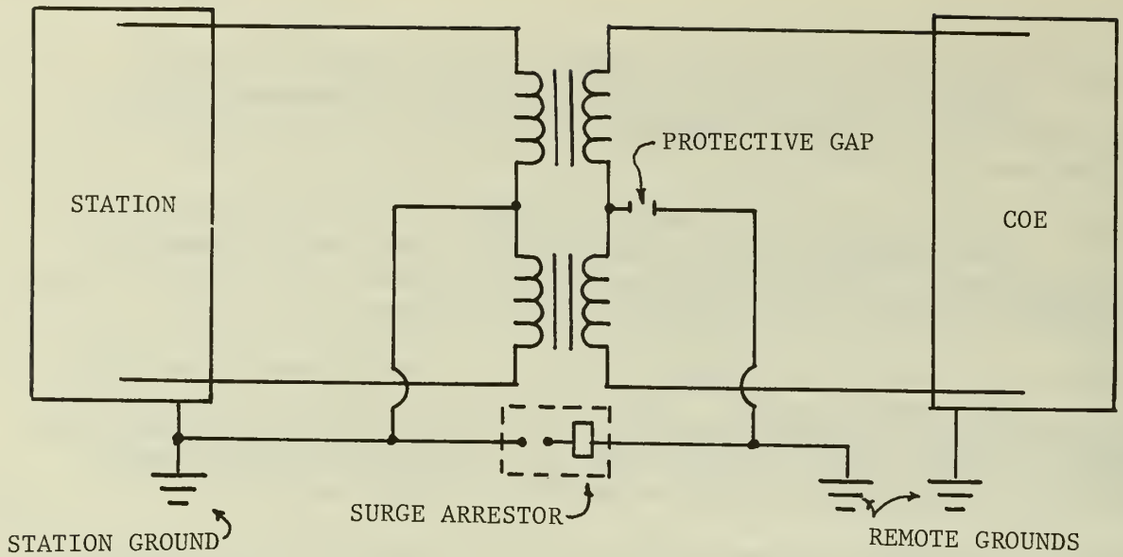
15.0763 Additional length of cable provided by the transformer windings may be sufficient to require relocation of load coils. The metallic impedance of a cable pair is altered only by the additional dc resistance and capacitance of the added cable length. Inductance added by the transformer is confined to the longitudinal circuit and does not affect the metallic circuit.

15.077 Neutralizing transformers are usually installed to reduce induced fundamental frequency voltage on the cable pairs. It can also reduce the voltage levels at harmonic frequencies on these cable pairs. Analog carrier systems can be operated through a neutralizing transformer. There is some additional insertion loss which must be considered when determining repeater locations for the carrier system.

15.0771 PCM carrier systems cannot be operated with voice grade neutralizing transformers. There is a PCM carrier system neutralizing transformer available which might be used where such systems exist. REA has not had operating experience at the time of this writing with these devices. Thus potential problems are unknown. There is a significant loss through the transformer at PCM carrier frequencies which must be considered when designing span line repeater spacings.

15.08 Isolation Trasformers: An isolation transformer presents a better way of reducing longitudinal current by interrupting the longitudinal circuit. This method, while effective, has a serious disadvantage. The characteristics of the telephone plant are changed and dc continuity is interrupted.

15.081 A schematic diagram of an isolating transformer is shown in Figure 20.



ISOLATION TRANSFORMER

FIGURE 20

15.082 This method is normally used for application on circuits that do not require dc for supervision. Among these are locally powered carrier systems and various telementry systems.

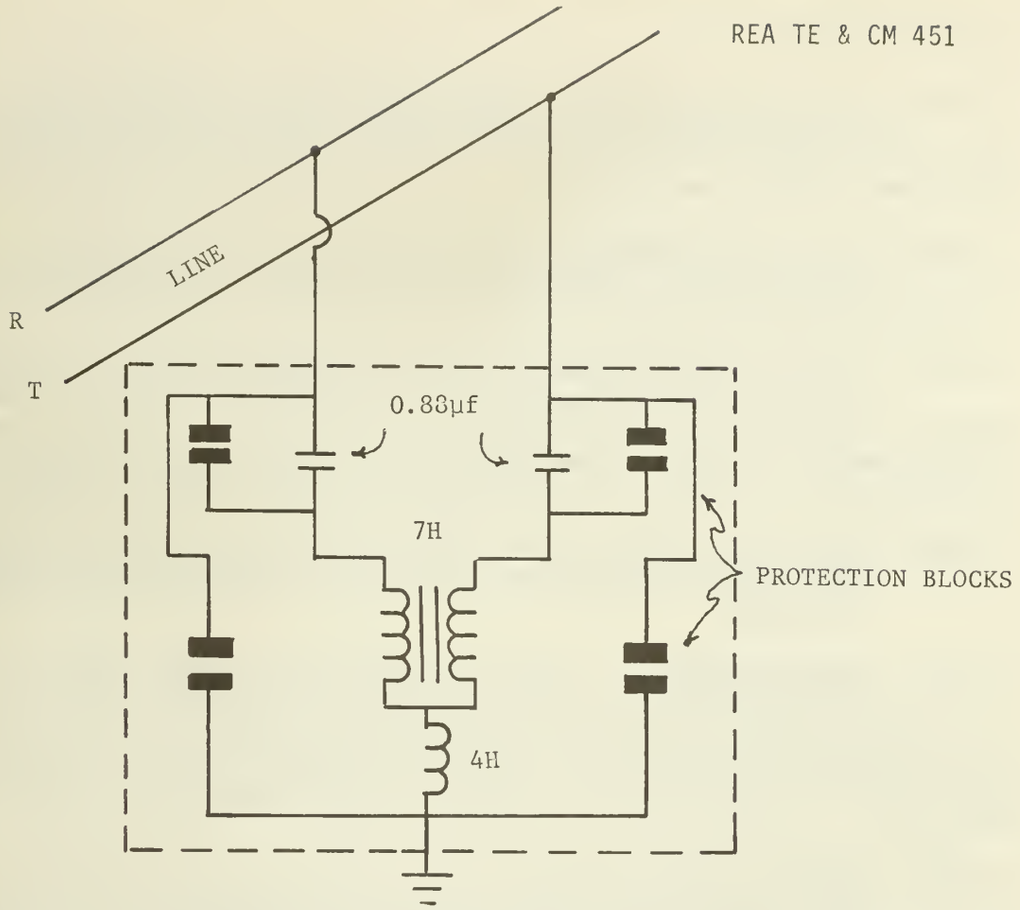
15.09 Drainage Reactors: Drainage reactors were originally designed to reduce electric field induced voltages on open-wire lines. Since electric coupling is usually high impedance, the impedance of the drainage unit can be fairly high and still produce good results.

15.091 Where magnetic induction is involved, the impedance of the drainage unit must be low compared with the circuit longitudinal impedance. This must be considered when thinking about applying a drainage unit as a mitigative measure.

15.092 A drainage reactor is two-winding well-balanced coil having a high mutual impendance between windings. An equal, but opposite, current flow in the two windings will result in cancellation of the coils longitudinal impedance. Thus, a low impedance path is provided from each side of the line (tip and ring) to the grounded midpoint as shown in Figure 21.

15.0921 Well balanced capacitors are used in series with each winding to prevent completion of the dc circuit across the line. Tuning drainage reactors are used with a system of capacitors and inductors arranged to provide a resonant circuit (usually at 60 Hertz) to ground.

15.0922 Drainage units composed of resistance and capacitance only were used before development of inductance and capacitance types used today.



108A, B or C DRAINAGE UNIT
INDUCTANCE CAPACITANCE TYPE

FIGURE 21

15.0923 Early types of drainage reactors with inductance and capacitance configuration (such as the W.E. 108A) caused high insertion loss at carrier frequencies. This problem was eliminated with the development of the W.E. 108B type.

15.093 Impedance to ground of a central office line circuit is approximately 100 ohms. If a drainage reactor installed at the CO is to effectively reduce the longitudinal voltage, its impedance must be low with respect to 100 ohms. When the need for series capacitance (which must be small to avoid signaling problems) in the drainage reactor is considered their application at the central office is not attractive.

15.094 Application of drainage reactors at or near the subscriber locations produces another set of potential problems. The longitudinal impedance of the station is high and the drainage device will effectively reduce the magnitude of longitudinal voltage.

15.0941 With the longitudinal voltage reduction, there will be an increase of the longitudinal current of the circuit. Thus, if there are any series unbalances existing in the telephone system near the subscriber location, an increase in noise may result.

15.0942 Where high frequency ringers (54, 60 or 66 Hertz) are used with divided ringing systems performance may be degraded where drainage reactors are installed.

15.0943 Another problem associated with drainage reactors is saturation. High longitudinal current may saturate the inductor and cause harmonic generation within the reactor. Thus, the reactor could reduce a problem such as gas tube firing while producing another in the form of audible noise.

15.095 Open wire plant is being phased out in the telephone industry. As this occurs there will be less use of drainage reactors for noise mitigation.

15.10 Ringer Isolators: Divided ringing and noisy telephone circuits go hand in hand. Where divided ringing is used, the unbalance of the station set due to a grounded ringer is a major factor in noise problems. Noise problems can occur even though high impedance ringers are used. Installation of a ringer isolator will produce a significant reduction in circuit noise.

15.101 Usually a ringer isolator cannot be used with two-party ANI systems where the tip-party identification is accomplished by detection of ground through a modified ringer. With the isolator in the circuit there is no path to ground unless ringing voltage is present.

15.102 There are devices available which combine a ringer isolator with an ANI detection device. These devices are not compatible with all metallic ANI detection systems.

15.11 Noise Mitigation - Power System

There are measures which may be applied by the power company for reduction of interference from power systems. Usually, a design which will minimize interference will also result in degradation of some other power system characteristics. Thus, reduction of interference is apt to be costly and otherwise unattractive to the power company. The truly optimal solution to an interference problem is one which results in the least cost and other disadvantages to both the power and telephone companies. Folowing are some possible power system procedures which might help achieve an optimum solution.

15.12 Load Balance: A method which can be applied to three-phase multi-grounded neutral systems is distributing the loads among the three phases so that the fundamental frequency currents of the phases are well-balanced along the entire length of the exposure. This would theoretically result in only the odd-triple harmonics appearing as residual current.

15.121 From a practical standpoint actually achieving a continuous phase balance is difficult. Utilization time for the various power system loads will rarely coincide and there is continuous change in overall loading throughout any given period.

15.122 A simple rearrangement of loads may prove beneficial at the time of completion. Three is no assurance that the loads may not shift in the near future and the interference return. Precise balancing of peak loads of the three phases at the substation will likely prove inadequate since loads on particular exposures within the power system may not coincide with the peaks at the substation.

15.13 Improved Neutral: Use of an additional or larger neutral is another possible method for interference reduction. This results in more residual current returning through the neutral rather than the earth. Additional cost to the power company should be compared to costs of other alternative solutions before application of this or any other method for interference reduction.

15.14 Capacitor Banks: When capacitor banks are found to be a factor, a possible solution is to relocate them to another position along the power line preferably nearer to the power substation. This can often result in a substantial reduction of harmonic magnitude. It can sometimes also shift the power system resonant frequency to a different value. If the point of relocation is to a point close to the substation the length of exposure to harmonic currents will be reduced even though resonances still exist and induced lengitudinal voltages on telephone circuits will be below objective levels. Another possible disadvantage with relocation is that the capacitors might be less effective in the power system at the new location.

15.141 Grounded Y capacitor banks provide a low impedance path to ground for harmonics thus increasing the residual harmonics. A possible remedy is to "float" the banks (disconnect the ground) or to reconnect the banks in delta configuration.

15.142 With delta connection, the capacitors must withstand a higher voltage (phase to phase) than with Y connection (phase to ground). This makes them more expensive.

15.143 "Floating Y" connections are considered inferior to grounded Y connections for the following reasons:

(a) Neutral voltage under unbalanced conditions shifts with floating Y connection and neutral-to-ground insulation is needed.

(b) Grounded Y connections are easier and less costly to fuse.

(c) Floating Y connections can produce serious over voltages, or phase reversals when one phase is open and can feed phase-to-ground loads at half voltage.

(d) There is a serious safety problem with floating Y connections. When a phase is open maintenance personnel may assume it to be dead while it is energized through the floating capacitor bank.

(e) Grounded Y connections provide a path to ground for surges.

15.144 A resonant shunt may be installed in the neutral connection of the capacitor bank between the tie point of the capacitors and ground. Inductance is added to lower the resonant frequency value to one which will induce less interference in the telephone systems.

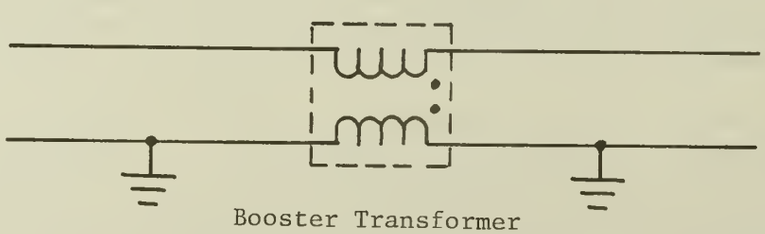
15.145 There are some low voltage distribution systems that use floating capacitor banks to minimize power system interference. When adequate safeguards are provided to prevent serious power system problems and to protect personnel, this form of mitigation may represent an alternate solution to an interference problem.

15.15 Resonant Shunts: Installation of resonant shunts or filters may provide the only solution to some noise cases such as those resulting from large, noisy rectifier installations. This approach can have some disadvantages which might offset any beneficial effects.

15.151 In addition to the added costs, the design of these filters is quite difficult. This is due to the changing, nonlinear characteristics of the power systems.

15.152 In some cases, installation of a resonant shunt will provide the desired suppression of the harmonic(s) for which designed only to increase the interference from another harmonic.

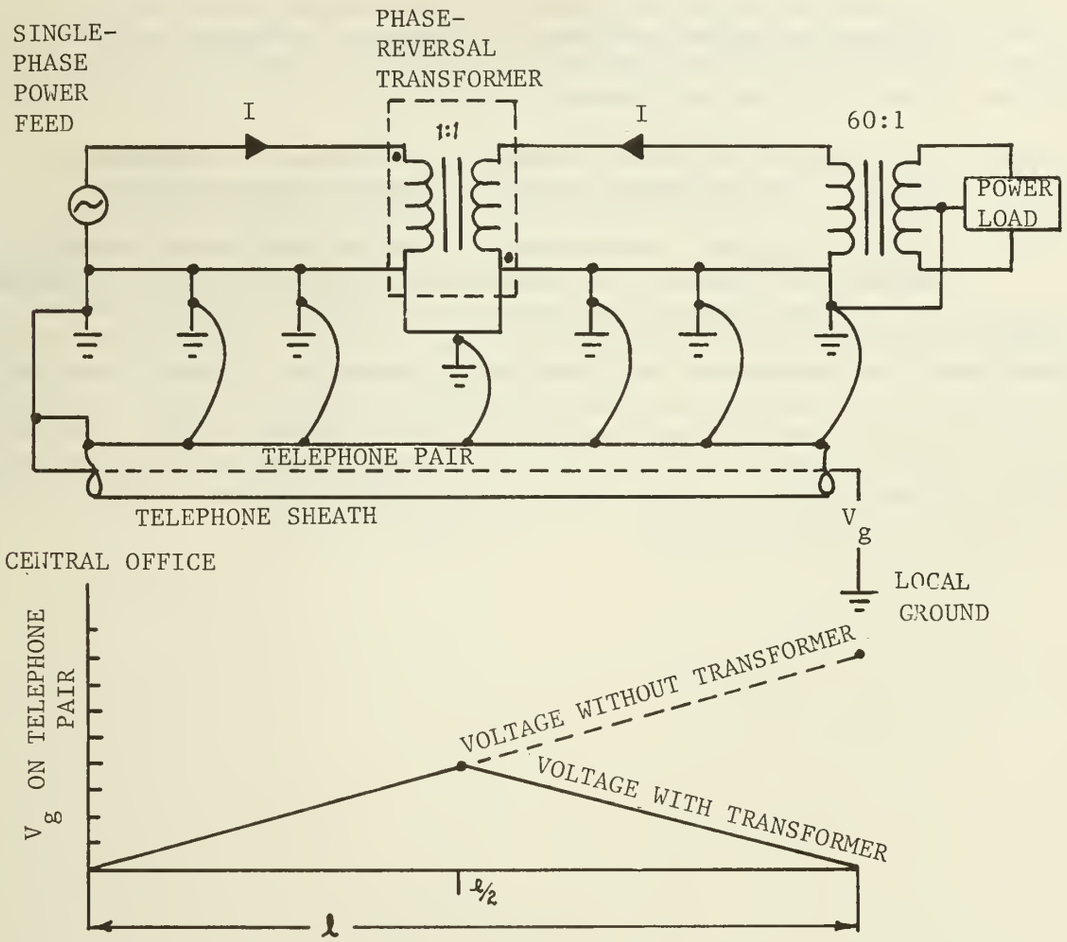
15.16 Booster Transfomers: Amplication of booster transformers is another method which can help reduce interference. This is accomplished by winding the power line and neutral wires into transformer coils as shown in Figure 22. A voltage is thus induced in the return path with a direction and magnitude such that the current is constrained to flow in the neutral conductor rather than the earth. This method is effective only when low impedance grounds are removed from that section of the exposure near the transformer. Installation of a booster transformer also has the undesired effect of another series element in the power line.



Booster Transformer

FIGURE 22

15.17 Phase-Reversal Transformer: Interference may also be effectively reduced through installation of a phase-reversal transformer approximately midway along a power line as illustrated in Figure 23. The induced voltage profile shows the theoretical reductions of maximum induced voltage. Again, there is the probelm of an added series element in the power system and the cost of the installed transformer.



VOLTAGE PROFILE FOR UNIFORM EXPOSURE

Phase-Reversal Transformer

FIGURE 23

15.18 Summary: There are various methods available for reducing the influence of the power system, the susceptibility of the telephone plant or the coupling between them. The most effective means of achieving compatibility between the telephone and the power system is through the inductive coordination process.

15.181 There will be unusual situations where the only practical solution to a noise problem will be the installation of additional elements or devices into either the power plant, the telephone plant, or both, which will reduce or eliminate the interference. All alternatives should be considered with their effects on power and telephone system reliability, performance, and associated economic impact.

15.182 All modifications for purposes of mitigation have undesirable effects on either the power or telephone system in which they are placed. Addition of series elements or devices is equally of concern to both power and telephone engineers.

15.183 The ideal solution must consider operational and maintenance factors as they relate to the economics of each system.

15.19 Carrier Systems: There will occur situations where there is no practical means of mitigation for either the power or telephone companies or, a noise problem has been mitigated but a few circuits in the telephone system still have excessive noise. A trunk or subscriber carrier system should be considered as a solution. Effects of harmonic interference are minimal at carrier frequencies. The voice frequency drop can be maintained in lengths short enough to have low power influence where exposed to parallel power systems. The application of carrier may not be satisfactory if there is excessive 60 Hertz induced longitudinal voltage present. This voltage should first be reduced. (See paragraph 15.07)

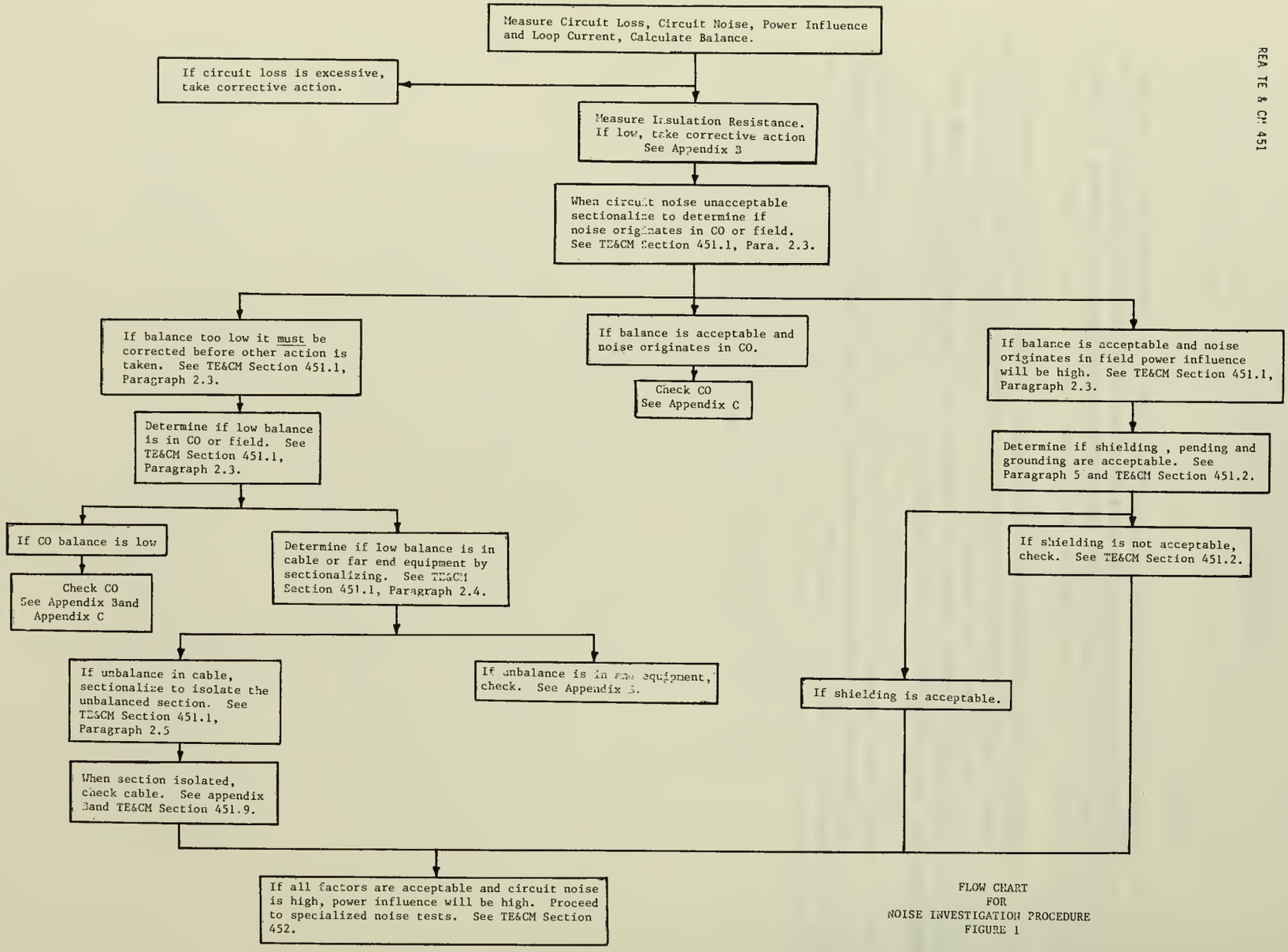
APPENDIX A
FLOW CHART FOR NOISE INVESTIGATION PROCEDURE

1. GENERAL

1.1 Figure 1 presents a flow chart for a noise investigation procedure. It is designed to provide a craftsperson a step-by-step approach to the initial noise investigation. Do not make assumptions and bypass any steps for the one passed might provide the solution.

1.2 Although many problems will be solved there is always a possibility that after completing the initial investigation, it will be necessary to proceed to specialized techniques which are discussed in TE&CM Section 452. Results of all measurements should be recorded so there will be no need for repeating any steps before proceeding with the specialized measurements.

1.3 The initial measurement shown in the first box of the flow chart will usually be completed at the subscriber location by maintenance forces responding to a noise complaint.


Measure Circuit Loss, Circuit Noise, Power Influence and Loop Current, Calculate Balance.
If circuit loss is excessive, take corrective action.
Measure Insulation Resistance. If low, take corrective action See Appendix B
When circuit noise unacceptable sectionalize to determine if noise originates in CO or field. See TE&CM Section 451.1, Para. 2.3.
If balance too low it must be corrected before other action is taken. See TE&CM Section 451.1, Paragraph 2.3.
If balance is acceptable and noise originates in CO.
If balance is acceptable and noise originates in field power influence will be high. See TE&CM Section 451.1, Paragraph 2.3.
Check CO See Appendix C
Determine if low balance is in CO or field. See TE&CM Section 451.1, Paragraph 2.3.
Determine if shielding , pending and grounding are acceptable. See Paragraph 5 and TE&CM Section 451.2.
If CO balance is low
Check CO See Appendix B and Appendix C
Determine if low balance is in cable or far end equipment by sectionalizing. See TE&CM Section 451.1, Paragraph 2.4.
If shielding is not acceptable, check. See TE&CM Section 451.2.
If unbalance in cable, sectionalize to isolate the unbalanced section. See TE&CM Section 451.1, Paragraph 2.5
If unbalance is in far end equipment, check. See Appendix B.
If shielding is acceptable.
When section isolated, check cable. See appendix B and TE&CM Section 451.9.
If all factors are acceptable and circuit noise is high, power influence will be high. Proceed to specialized noise tests. See TE&CM Section 452.

FLOW CHART
FOR
NOISE INVESTIGATION PROCEDURE
FIGURE 1

APPENDIX B
CHECK LIST OF
POTENTIAL NOISE FACTORS

1. GENERAL

1.1 The following check lists are provided to assist in locating the major factor(s) contributing to a noise problem. They are grouped into categories that are readily identified during noise isolation procedures.

2. INSULATION RESISTANCE

2.1 Open Wire: When recorded results from insulation resistance tests have indicated leakage to ground exists, the following items should be checked.

2.11 Drainage Units: Inspect for clean carbons. Replace carbons with new ones if necessary. Replace unit with one known to be good. Consideration might be given to replacing carbon arrestors with gas tube arrestors where possible.

SAFETY NOTE: Disconnecting the drainage unit may result in a voltage rise on the line.

2.12 Carrier System Low Pass Filters: Inspect for clean carbons and proceed as in Paragraph 2.11 above.

2.13 Carbon Blocks: Inspect all carbon blocks in the entire line. Clean or replace dirty blocks. Replace any damaged or bad blocks.

2.14 Tree Limbs: Inspect entire length of line. Trim as required.

2.15 Broken Insulators: Inspect. Replace broken ones.

2.16 Crows Nests: Find and remove.

2.17 Spider Webs and/or Insect Nests at Station Protector: Inspect, kill spiders and insects, eliminate eggs, destroy webs and nests.

2.2 Cable Plant: When recorded results from insulation resistance tests have indicated leakage to ground exists, the following items should be checked.

2.21 Drainage Units: Inspect for clean carbons. Replace carbons with new ones, if necessary. Replace unit with one known to be good. Consideration might be given to replacing carbon arrestors with gas tube arrestors. Drainage units are usually not installed on cable plant.

SAFETY NOTE: Disconnecting the drainage unit may result in a voltage rise on the line.

2.22 Carrier System Low Pass Filter: Inspect the clean carbons and proceed as in Paragraph 2.21 above.

2.23 Carbon Blocks: Inspect all carbon blocks in the entire line. Clean or replace dirty blocks. Replace any damaged or bad blocks.

2.24 Spider Webs and/or Insect Nests: Inspect pedestals, station protectors and similar structures. Kill spiders and/or insects and eliminate eggs. Destroy webs and nests.

2.25 Underground Splices: Measure insulation resistance (between the nearest points in ready access or buried plant pedestal housings) to determine insulation level.

2.26 Water in Cable or Moisture: Determine its effect by measuring insulation resistance of pair tip-to-ground and ring-to-ground. Insulation should be high and values should be approximately equal for each conductor to ground.

2.27 Terminal Blocks: Inspect and clean.

2.28 Bridged Tap Isolators: Inspect by removing them to determine if they are a factor. Under some arrangements in the presence of high longitudinal induction these devices can generate harmonics.

3. CENTRAL OFFICE

3.1 When recorded results from noise isolation procedures have indicated that the major factor contributing to the noise problem is in the central office the following items should be checked.

3.11 Heat Coils: Measure the resistance. Resistance should be less than 0.1 ohms. Replace the heat coils with units known to be good.

3.12 Central Office Ground: Measure with ground resistance meter. Value should be less than one ohm.

3.13 Battery Supply Ground: Positive terminal of the main battery should be connected directly to the main central office ground and should be isolated electrically from all other ground points. Check that connecting bolts are tight and connections are clean and corrosion free.

3.14 Coupling in Battery Leads: Common batteries for signaling and talking can conduct voice frequency noise from noisy circuits to other circuits. When this is determined to be the case, decentralized filters of the L configuration can be used. The L filter configuration has component values of approximately one millihenry and 7,000 microfarads. This condition will rarely be found since specifications require battery filters in central offices.

3.15 Mainframe Coupling: Signaling and battery feed relays sharing the same frame may conduct noise in cable pairs due to insufficient decoupling in the battery between the battery feed and signaling relays. This is basically "crosstalk" noise.

3.16 Electronic Loop Extenders: High induced longitudinal 60 Hertz voltage can saturate these devices and they will generate harmonics in the voice frequency range.

3.17 Additional Information on Central Office Unbalance: Refer to Appendix C for discussion of the sources of unbalance in the central office and associated equipment.

4. STATION EQUIPMENT AND WIRING

4.1 When recorded results from noise isolation procedures have indicated that the major factor contributing to the noise problem is in the station equipment and/or wiring the following items should be checked.

4.11 Carbon Blocks: Inspect. Clean or replace dirty blocks. Replace damaged or defective carbon blocks.

4.12 Station Fuses: Check for corrosion. Clean fuse holder contacts. Replace both fuses with units known to be good.

4.13 Spider Webs and/or Insect Nests: Inspect station protectors. Kill spiders and/or insects and eliminate eggs. Destroy webs and nests.

4.14 Station Wiring: Inspect wiring between station and station protector.

4.15 Ringers: Check that the ringer is a high impedance type. Determine that the ringer has been properly wired such as being connected for bridged ringing when it is being used in a bridged ringing application. Where divided ringing is used, check to see that all ringers on the line are balanced for frequency and location. Improper connection of customer owned equipment may also be a problem.

5. OUTSIDE PLANT

5.1 When recorded results from noise isolation procedures have indicated that the major factor contributing to the noise problem is in a specific part of the outside plant, the following plant items should be checked.

5.2 Open Wire:

5.21 DC Loop Resistance Unbalance: This should not be a factor, except where the open wire portion of the loop is very long. A T&R reversal will prove conclusively if the resistance unbalance is a contributing factor. Refer to Paragraph 15.04 of TE&CM Section 451 for a discussion of resistance unbalance.

5.22 Splices and Splice Sleeves: Inspect all splices. Replace all splices or splice sleeves known or suspected to be defective.

5.23 Open Wire Taps: Continue isolation procedures to isolate the location of the problem.

5.24 Bridged Tap Isolators: These devices are not designed for use on open wire. Search for and remove any that are found.

5.25 Line Sag: Check for equal line sag. Correct where necessary.

5.26 Transposition Errors: Check actual line against applicable transposition scheme. Correct any irregularities found.

5.3 Cable:

5.31 DC Loop Resistance Unbalance: Measure resistance unbalance with a wheatstone bridge as shown in Figure 7 of TE&CM Section 451.3. Refer to Paragraph 15.09 of TE&CM Section 451 for a discussion of the effects of resistance unbalance.

5.32 Splice Connectors: Inspect all splices. Replace all splices found or suspected to be defective.

5.33 Capacitance Unblance: Measure the capacitance unbalance of the pair by using the procedure shown in Figure 4 of TE&CM Section 451.3. It is suggested that the test length be limited to 4.5 to 6.0 kilofeet (loading section length). The magnitude of capacitance should meet limiting values in applicable cable specifications.

NOTE: See TE&CM Section 451 for a discussion of determining capacitance unbalance from longitudinal balance measurements. This technique utilizes test equipment less expensive and complex than that required for direct measurement of capacitance unbalance.

APPENDIX C
CENTRAL OFFICE EQUIPMENT

1. The following discussion shows where unbalances can occur in central office and associated equipment installed on the office side of the MDF.

1.1 Figure 1a shows a connector or transmission bridge in the talking condition. An unbalance can occur in the battery feed relay(s) and or in the capacitors.

1.11 Modern battery feed relays are usually well balanced. Occasionally some older equipment will be found where relay unbalance exists. These should be replaced with better balanced relays.

1.12 Some of the modern electronic offices utilize repeating coil coupling between the switching equipment and the cable pair. These should also be relatively well balanced.

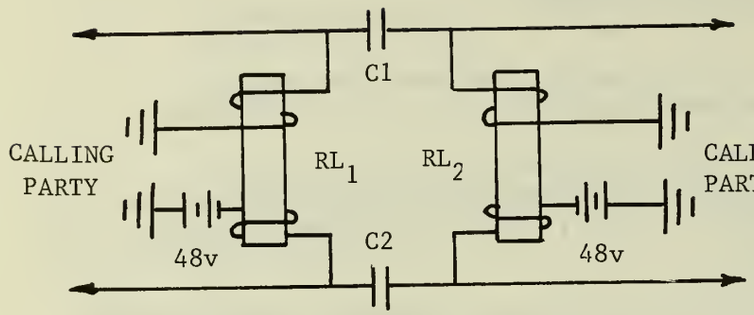
1.2 Bridge type long line adapter equipment (Figure 1b & c) may occasionally be found to have insufficient balance. A repeating coil type long line adapter unit will provide better balance.

1.3 Relays providing talking battery during revertive call connections may occasionally be found unbalanced. This is because a different relay (signaling type) other than a battery feed, which is usually well balanced, may be providing the talking battery.

1.4 Relay saturation resulting in noise may sometimes be encountered. This occurs when very high fundamental frequency induction in the longitudinal circuit has a path to ground through the line relay in the idle condition (or the battery feed relay in the talking condition) and the relay core. The relay windings become non-linear and create harmonics of the fundmental 60 Hertz frequency which are heard on the line as noise. A drainage unit (See Paragraph 15.09) installed at a suitable location will often (not always) correct for this, not because the unit is a noise filter, but because it reduces the 60 Hertz current in the CO equipment and thus prevents saturation. Another method for controlling the 60 Hertz current is the installation of a longitudinal choke at the CO. This is discussed in Paragraph 15.06.

1.5 Repeating coils used for trunk circuits are normally well balanced if <u>correctly</u> wired in. No known noise problems have been attributed to repeating coils.

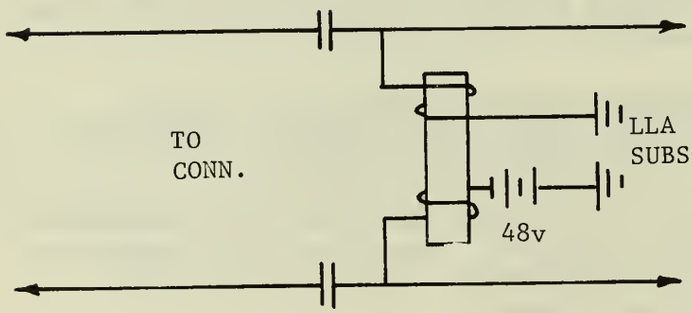
1.51 DX signaling, a dc signaling system for use on trunks has very good balance if properly wired. Check to determine that the 250 ohm balancing resistor and the transmission capacitors <u>are</u> in place. A basic diagram for the unit properly wired is shown in Figure 2. DX signaling is not normally susceptible to relay chatter, although some cases have been reported in the presence of high longitudinal induction.



IF TRANSMISSION CAPACITOR C1 IS NOT WELL MATCHED WITH TRANSMISSION CAPACITOR C2 NOISE CAN RESULT

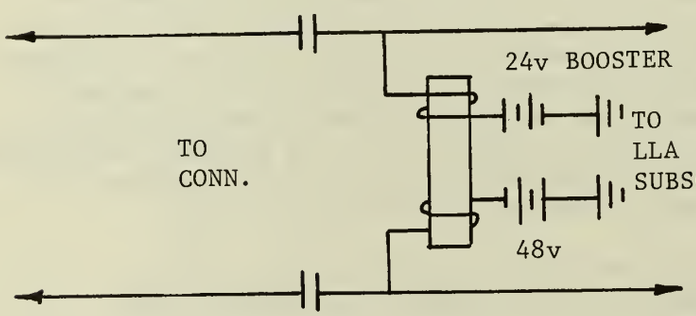
IF THE IMPEDANCE OF THE WINDINGS OF EACH TALKING RELAY RL_1 AND RL_2 IS NOT WELL BALANCED WITH RESPECT TO GROUND NOISE CAN RESULT

A. TYPICAL TRANSMISSION BRIDGE IN C.O. CONNECTOR CIRCUIT



IF THE IMPEDANCE OF THE TALKING BATTERY RELAY WINDINGS IS NOT WELL BALANCED WITH RESPECT TO GROUND NOISE CAN RESULT

B. TYPICAL TRANSMISSION BRIDGE FOR LONG LINE ADAPTER (HALF-BRIDGE)



1. SAME COMMENT AS (B) ABOVE FOR RELAY WINDINGS
2. IF 24v BOOSTER IS NOT WELL FILTERED NOISE CAN RESULT

C. TYPICAL LLA WITH 72 VOLTS (48v C.O. + 24v BOOSTER)

FIGURE 1 TYPICAL TRANSMISSION BRIDGE CIRCUITS FOR LOOP CALLS

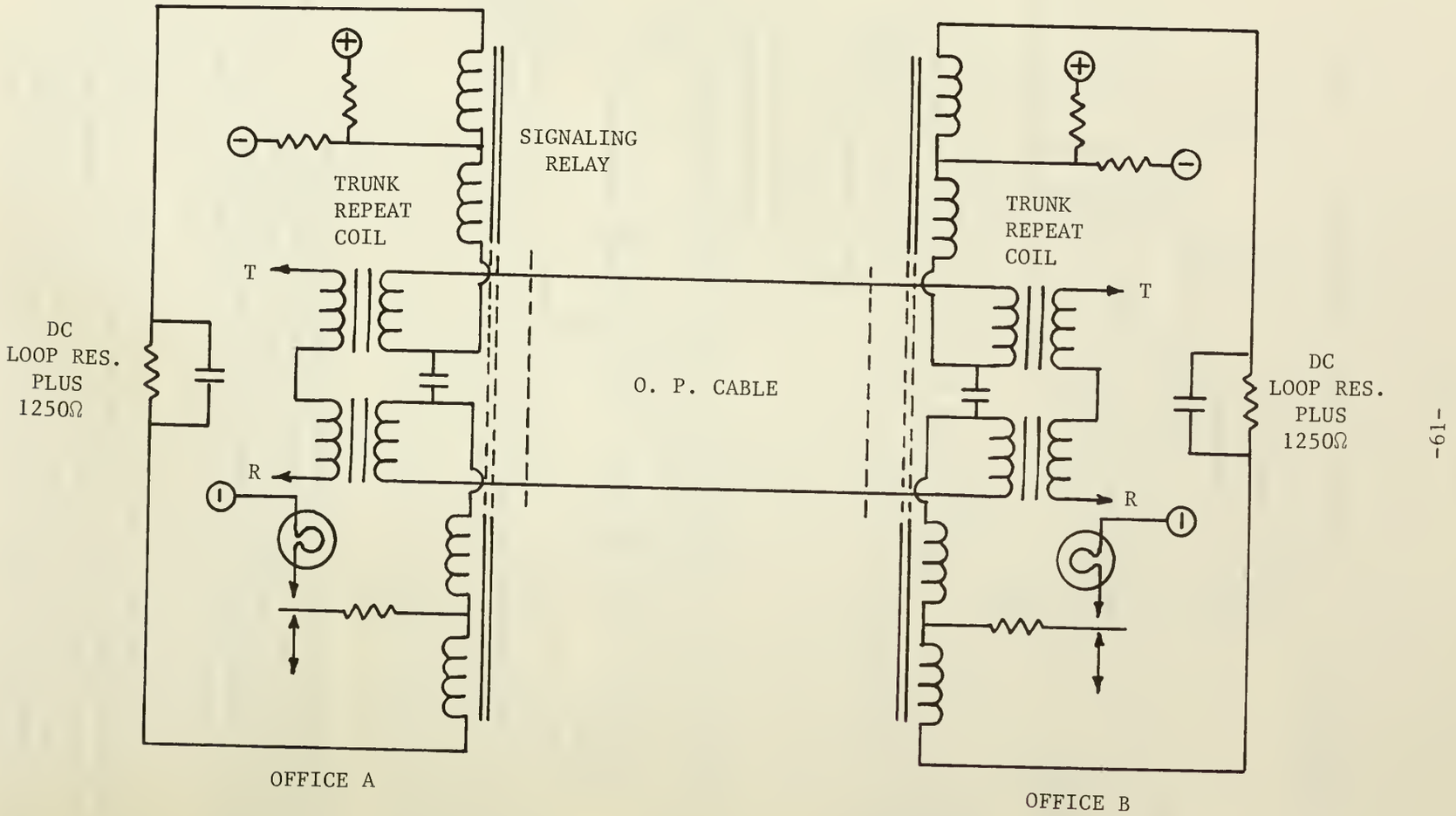


FIGURE 2 DX SIGNALING. PARTIAL SCHEMATIC IN TALKING CONDITION

1.52 Older type CX signaling is shown in Figure 3 in its basic form. This signaling system provides good balance at higher 60 hertz harmonic frequencies, if thump coils are correctly wired-in, but is inherently unbalanced at the low frequencies, particularly 180 hertz and lower. In the past, much of the application for CX signaling was for phantom circuits. CX is no longer the recommended system and its use should be avoided.

1.521 Where CX signaling is used, check for a ground on the line side of the repeating coil. If ground is present, remove. Do this at both ends of the trunk. The ground is not required for either signaling or transmission reasons with non-phantomed circuits. Removing this ground eliminates the noise path which will reduce noise due to outside plant resistance unbalance.

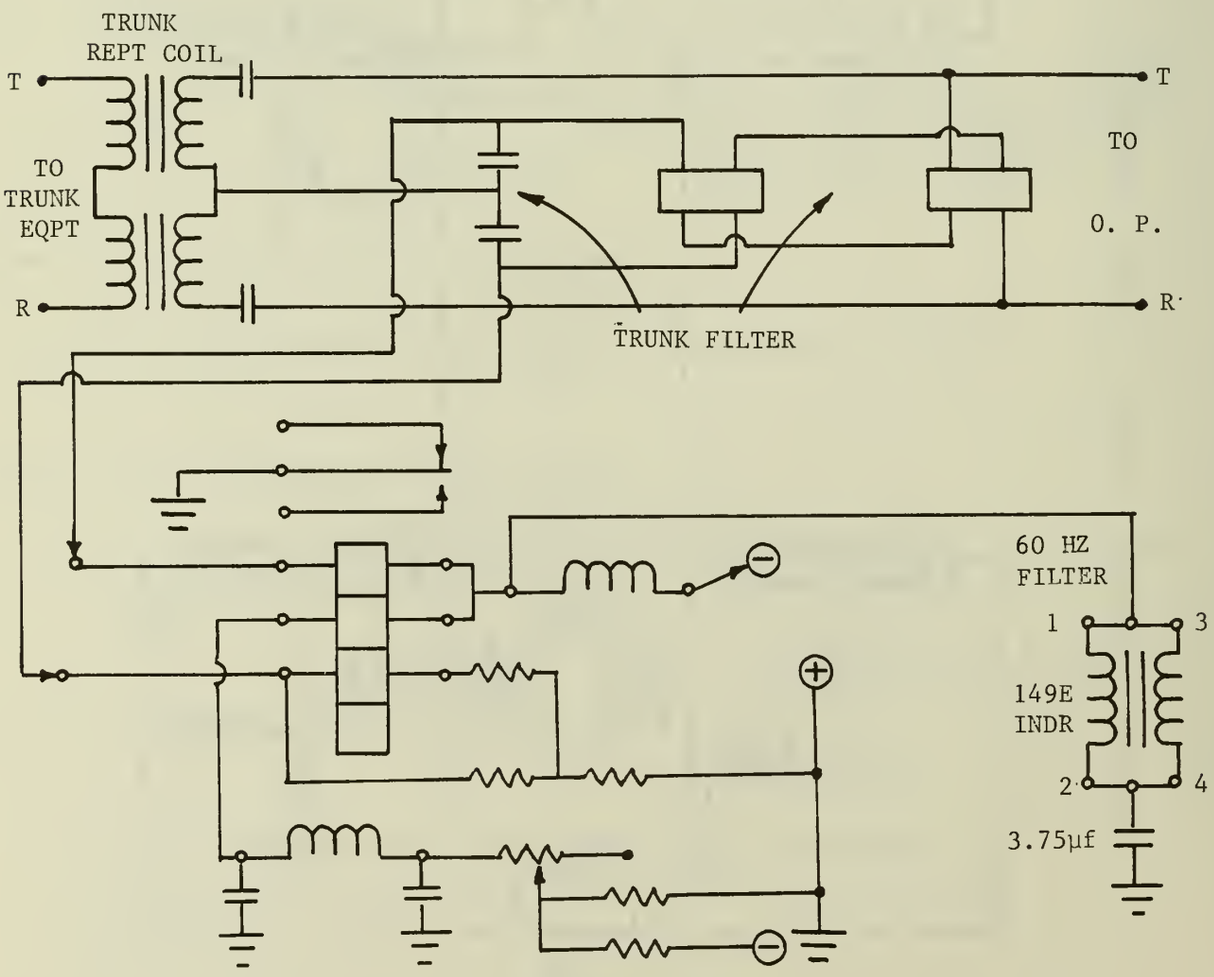


FIGURE 3 CX SIGNALING BASIC CONFIGURATION. ONE END ONLY

1.522 Existing CX equipment can display relay chatter in the idle trunk condition in the presence of few volts to ground of 60 Hertz induction at the signaling equipment terminals. The use of 60 Hertz filters such as shown in Figure 3 will correct relay chatter of buzzing in the idle condition of the voltage to ground is less than 40 volts. Filters are required at both ends.

1.53 SX signaling equipment inherently gives good balance. Check to determine that it is wired correctly. It is also subject to relay chatter in the idle condition the same as CX equipment. SX will probably operate with no buzz or relay chatter by treating the signaling ends with the 60 Hertz filters discussed in Paragraph 1.522 above and shown in Figures 4A & 4B. Filters are required at both ends.

1.54 Loop dial signaling equipment may still be found which is unbalanced. Unbalanced relays facing the cable side should be replaced with balanced relay units. On some modern loop dial units occasionally a 1,500 ohm resistor may be found connected from one side of the line to ground, for signaling reasons only, causing noise. This unbalance can be corrected by replacing the resistor with a decade box. Otherwise, loop dial signaling results in a very acceptable noise level, again, if properly wired.

1.55 E-6 type voice frequency repeater equipment works extremely well with DX, SX CX, and Loop Dial signaling systems. An E-6 type repeater can produce noise through saturation. Should the signaling equipment be unbalanced (by reason of incorrect wiring, natural unbalance, etc.) a portion of the noise-to-ground low frequency voltage is across the tip and ring sides or metallic path across the repeater input terminals. This induction saturates the repeater which creates its own harmonics like the line relay (See Paragraph 1.4 above). Presence of such a condition may be easily checked by observing on a noise measuring set whether the magnitude of circuit noise is reduced by the amount of repeater gain (or approximately so) when the repeater is temporarily removed from the circuit. If the reduction is much greater than the repeater gain, repeater saturation is indicated. When the unbalance is removed, this problem is entirely eliminated. Saturation may also occur with certain types of toll ticketing equipment.

1.56 Solid state loop extender and trunk equipment have been developed and are being used in many offices. All these devices are usually well balanced but noise problems can occur due to saturation in the presence of high induced longitudinal voltage. REA attempts to minimize the incidence of this type problem through a simulated longitudinal induction test in the specifications for these devices.

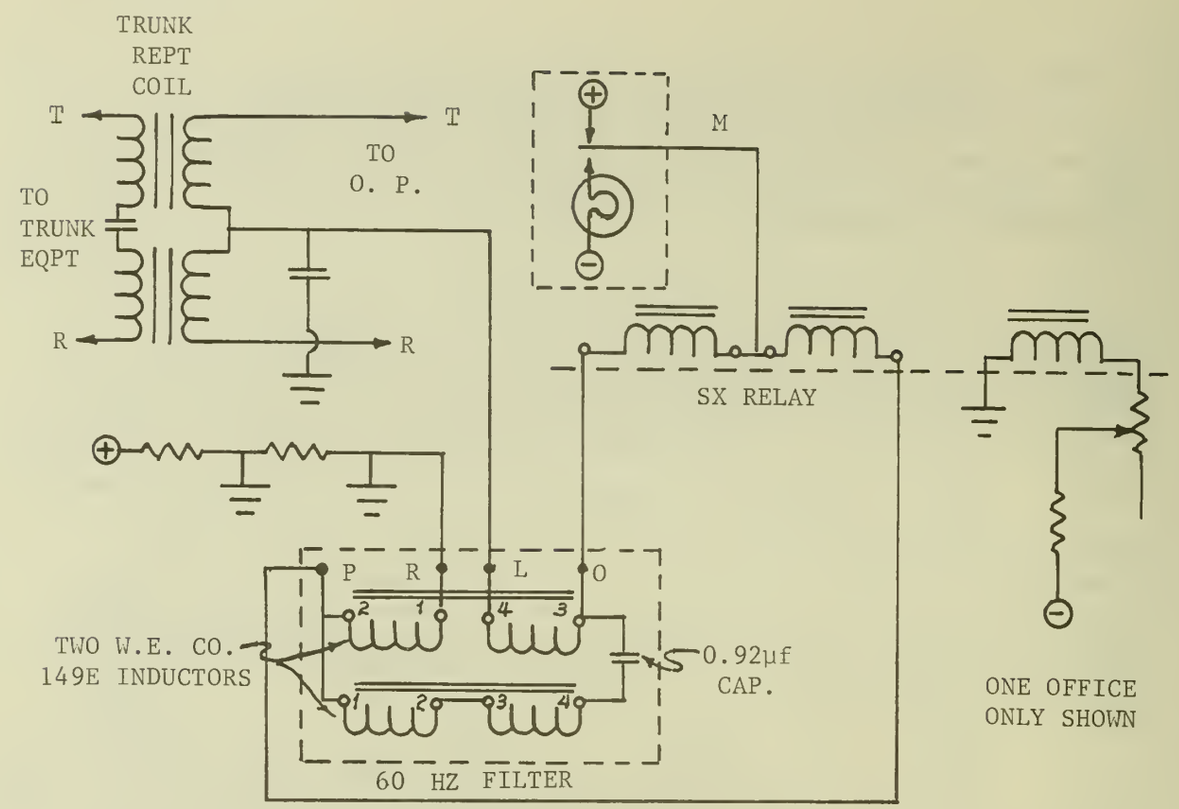


FIGURE 4A SX SIGNALING WITH 60 HZ FILTER FOR ELIMINATING RELAY CHATTER

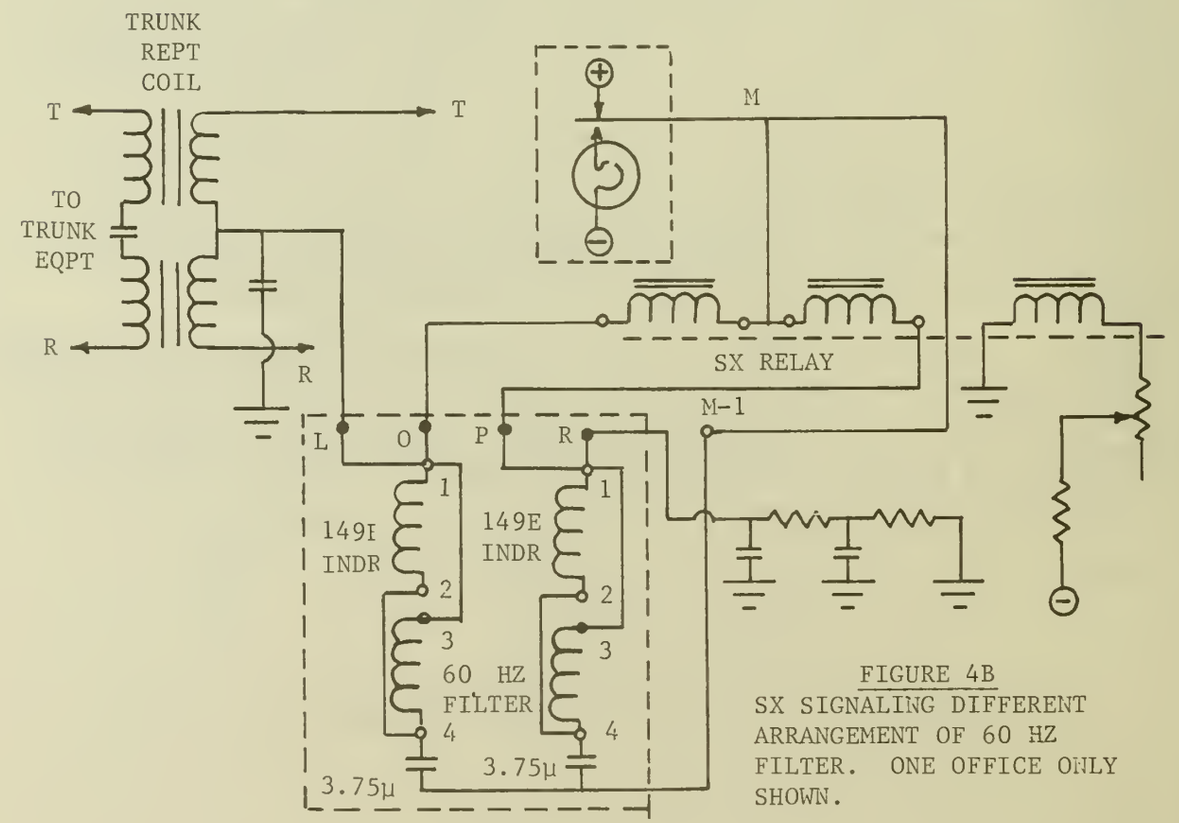


FIGURE 4B
SX SIGNALING DIFFERENT ARRANGEMENT OF 60 HZ FILTER. ONE OFFICE ONLY SHOWN.

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DOC.
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BOOKSTACKS
DOCUMENTS

Rural Electrification Administration
Telecommunications Engineering and Construction Manual

Section 451
Issue No. 2
Addendum No. 1
September 1981

TELEPHONE NOISE MEASUREMENT AND MITIGATION

Purpose: The purpose of this addendum is to replace Appendix A to TE&CM 451, Telephone Noise Measurement and Mitigation, with this revised Appendix.

Attachment

DEPOSITORY
NOV 5 1981
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

APPENDIX A
NOISE INVESTIGATION GUIDE

1. GENERAL

1.1 This revision presents a step-by-step flow chart for noise investigations for use of craftspeople in the field. It is organized so that each page provides a single link in the total investigation which directs the user to the next link in the investigation.

1.2 It is essential that the results of all measurements be recorded for reference as the investigation progresses.

1.3 Figures and Tables are referred to as appropriate in the flow charts.

2. HOW TO USE THE GUIDE

2.1 The first measurements should be completed at the subscriber location. To reduce travel time the measurements shown below are best completed during this first visit of the investigation to the subscriber location.

2.1.1 If loop checking equipment is being used complete measurements covered by Charts 1, 2, 3, 4 & 7.

2.1.2 If a noise measuring set is used complete measurements covered by Charts 1, 2, 3, 4, 7 & 14.

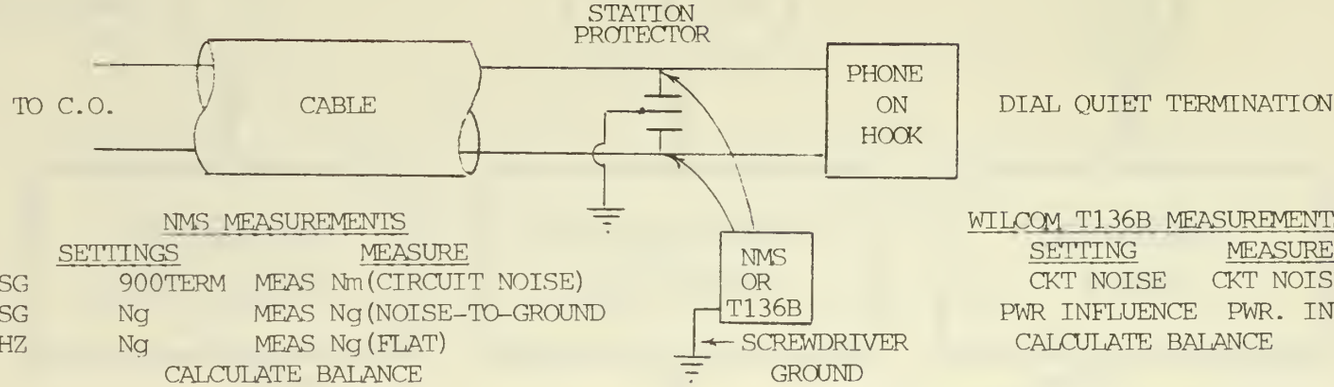
2.1.3 When a noise measuring set and spectrum analyzer is available complete measurements covered by Charts 1, 2, 3, 4, 7, 9, 14 & 17.

2.2 Start analyzing the recorded results at Chart 1. Then proceed to the Chart indicated below the appropriate level for the next step.

2.3 An * on the Chart indicates a measurement which may be completed with loop checking equipment.

3. TEST EQUIPMENT

3.1 The use of specific types of specialized test equipment manufactured by Wilcom Products, Inc. are described in the Noise Investigation Guide. These items are generally used throughout the Telecommunications industry and in some cases are, to the best of our knowledge, the only ones specifically designed for these applications. This is not an endorsement of these products by REA. Any test equipment capable of performing the measurements described may be used in lieu of those identified herein.



NMS MEASUREMENTS

SETTINGS		MEASURE
C-MSG	900TERM	MEAS Nm (CIRCUIT NOISE)
C-MSG	Ng	MEAS Ng (NOISE-TO-GROUND
3-KHZ	Ng	MEAS Ng (FLAT)

CALCULATE BALANCE

WILCOM T136B MEASUREMENTS

SETTING	MEASURE
CKT NOISE	CKT NOISE (Nm)
PWR INFLUENCE	PWR. INFL. (PI)
CALCULATE BALANCE	

BALANCE=PWR. INFL. - CKT NOISE

PWR INFL = Ng + 40

NOISE MEASUREMENT SUBSCRIBER LOCATION
FIGURE 1

Chart *1

SUB

* Measure Power Influence C-Msg. Weighting

See TE&CM Section 451.

Test configuration shown on Figure 1, Page 53B.
See also notes on Page 53D.

Less Than 80 dBrnc	Between 80 & 90 dBrnc	Over 90 dBrnc
Go To Chart (2)	(2) (9)	(14)

*Measurements may be completed with Loop Checking equipment.

SAVE A TRIP

While at the subscriber location don't forget housekeeping of protector.

Check:

Station protectors: Kill insects and destroy eggs. Remove webs and nests. Note evidence of corrosion and clean.

Gas Tubes: Inspect. Replace damaged or *defective tubes.

Carbon Blocks: Inspect. Clean or replace dirty blocks. Replace damaged or defective carbon blocks.

Station Fuses: Inspect for corrosion. Clean fuse holder contacts. Replace both fuses with units known to be good.

*Identification of defective requires use of a gas tube checker.

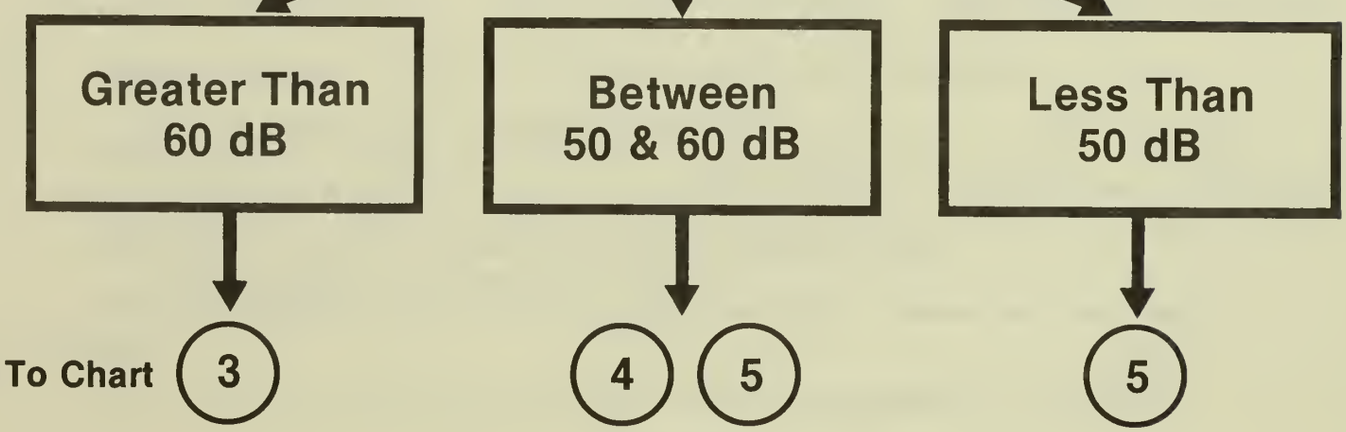
Chart *2

SUB

* Measure Balance PI - CN = BAL

See REA TE&CM Section 451.

Test configuration shown on Figure 1, Page 53B.



*Measurements may be completed with Loop Checking equipment.

TABLE I
INVERSE POWER SUMMATION

FIND DIFFERENCE, IN DBRNC, BETWEEN MEASUREMENT 1 & 3 (Nm) OF FIGURE 2 IN COLUMN A. ALGEBRAICALLY ADD THE VALUE FOUND IN COLUMN B FOR THIS DIFFERENCE TO RECORDED RESULTS OF MEASUREMENT 3 TO FIND NOISE DUE TO CONNECTOR BALANCE.

A	B	A	B	A	B	A	B	A	B
0.5	-9.1	3.5	0.9	6.5	5.4	9.5	9.0	12.5	12.2
1.0	-5.9	4.0	1.8	7.0	6.0	10.0	9.5	13.0	12.8
1.5	-3.8	4.5	2.6	7.5	6.6	10.5	10.1	13.5	13.3
2.0	-2.3	5.0	3.3	8.0	7.3	11.0	10.6	14.0	13.8
2.5	-1.1	5.5	4.1	8.5	7.8	11.5	11.2	14.5	14.3
3.0	0	6.0	4.7	9.0	8.4	12.0	11.7	15.0	14.9

NOTE: IF DIFFERENCE IS GREATER THAN 15DBRNC THE POSSIBILITY OF EQUIPMENT SATURATION SHOULD BE INVESTIGATED.

EXAMPLE 1

MEASUREMENT 1 (Nm) 15 DBRNC
MEASUREMENT 1 (NL) 30 DBRNC
MEASUREMENT 3 14.5 DBRNC

MEAS. 1 (Nm)	15.0	BAT 0.5	-9.1
MEAS. 3	- 14.5	MEAS. 3	+14.5
DIFF.	0.5	CONNECTOR NOISE	5.4
MEAS. 1 (NL)	30.0	PWR. INFL.	70.0
	+ 40.0	CONNECTOR NOISE	- 5.4
PWR. INF.L.	70.0	CONNECTOR BALANCE	64.5 DB.

EXAMPLE 2

MEASUREMENT 1 (Nm) 20 DBRNC
MEASUREMENT 1 (NL) 37 DBRNC
MEASUREMENT 3 7 DBRNC

MEAS. 1 (Nm)	20.0	BAT 13	12.8
MEAS. 3	- 7.0	MEAS. 3	+ 7.0
DIFF.	13.0	CONNECTOR NOISE	19.8
MEAS. 1 (NL)	37.0	PWR. INF.	77.0
	+40.0	CONNECTOR NOISE	-19.8
PWR. INF.L.	77.0	CONNECTOR BALANCE	57.2 DB

Chart *3

*Measurements may be completed with Loop Checking equipment.

While at the central office <u>don't forget to check ground connections</u>.

1. Are they solid? Tighten if loose.
2. Is positive battery terminal connected directly to ground and isolated electrically from all other ground points?
   SXS Office - connected to MDF ground bar.
   Digital Office - connected to ground window points
3. Is there a direct connection between the main ground bar and the ground bar in the main ac power panel.
4. Refer to REA TE&CM Section 810 for further details.

Chart *4

SUB

*See REA TE&CM Section 451.

Test configuration shown on Figure 1, Page 53B.

Circuit Noise

Less Than 20 dBrnc

Go To Chart 21

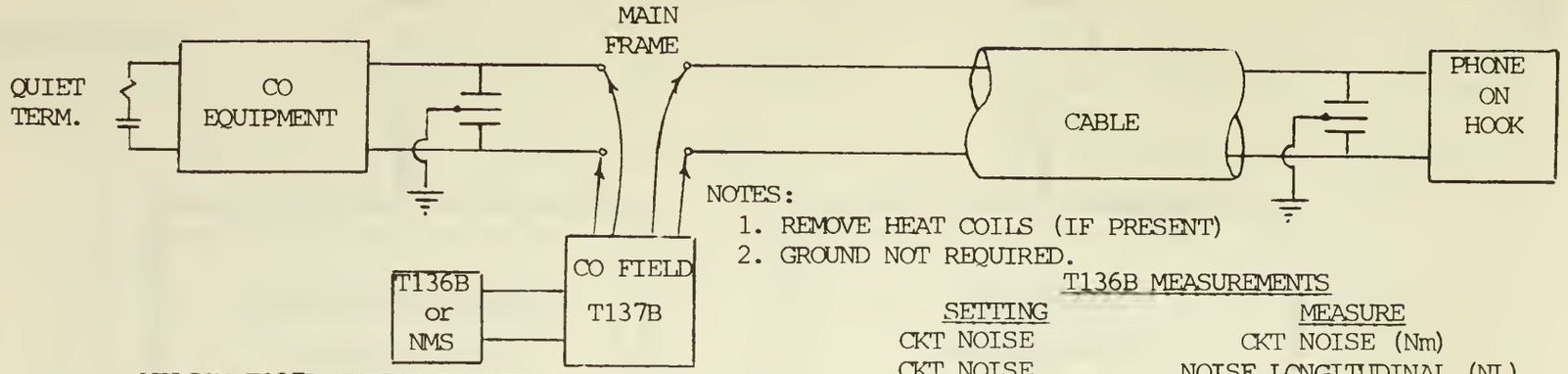
Between 20 & 26 dBrnc

5 9

Greater than 26 dBrnc

5

*Measurements may be completed with Loop Checking equipment.



NOTES:
1. REMOVE HEAT COILS (IF PRESENT)
2. GROUND NOT REQUIRED.

T136B MEASUREMENTS

SETTING	MEASURE
CKT NOISE	CKT NOISE (Nm)
CKT NOISE	NOISE LONGITUDINAL (NL)
	CALCULATE BALANCE

NMS MEASUREMENTS

	SETTING	MEASURE
C-MSG	900 TERM MEAS	Nm(CKT NOISE)
C-MSG	900 TERM MEAS	NOISE LONGITUDINAL (NL)
		CALCULATE BALANCE

WILCOM T137B SWITCH POSITIONS

	MEAS. NO. 1	MEAS. NO. 2	MEAS. NO. 3
TERM:	OFF	OFF	OFF
LONG. CURRENT:	OFF FOR CKT. NOISE ON FOR NOISE LONG.	OFF FOR CKT. NOISE ON FOR NOISE LONG.	OFF FOR CCT NOISE
DIAL. MEAS: FUNCTION:	MEAS. POSITION 1.	MEAS. POSITION 2	MEAS. POSITION 4

$$\text{TRUE EQUIPMENT BALANCE} = (\text{NOISE LONG.}+40) - 10\log_{10}\left(1\log_{10}^{-1}\left(\frac{\text{CKT NOISE (MEAS.1)}}{10}\right) - 1\log_{10}^{-1}\left(\frac{\text{CKT NOISE (MEAS.3)}}{10}\right)\right)$$

NOTE: THE INVERSE POWER SUMMATION CAN BE SOLVED WITH TABLE I. (PAGE 53F)

ISOLATION MEASUREMENT AT MDF
FIGURE 2

CO

*

See REA TE&CM Section 451.1.

Isolation Measurement at MDF

Test configuration shown on Figure 2, Page 53 J. See also the notes on Page 53H.

Problem in Central Office

Problem in Cable?

Go To Chart 6

Go To Chart 7

*Measurements may be completed with Loop Checking equipment.

TABLE II

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	24 GAUGE SHIELDS: 5mil CU, 8mil Al & 7mil 194															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	0.8	0.2	0.8	0.1	0.8	0.1	0.8	0.1	0.8	0.1	0.7	0.1	0.7	-	0.7	-
2	1.8	0.6	1.8	0.5	1.8	0.5	1.7	0.4	1.7	0.3	1.6	0.2	1.6	0.2	1.6	0.1
3	2.6	1.1	2.5	1.0	2.5	0.9	2.5	0.7	2.4	0.5	2.4	0.4	2.3	0.3	2.3	0.3
4	3.2	1.5	3.1	1.3	3.1	1.2	3.0	0.9	3.0	0.8	2.9	0.6	2.9	0.5	2.8	0.4
5	3.6	1.9	3.6	1.7	3.6	1.5	3.5	1.2	3.4	1.0	3.4	0.8	3.3	0.6	3.2	0.5
6	4.0	2.2	4.0	2.0	3.9	1.8	3.8	1.4	3.8	1.2	3.7	1.0	3.6	0.8	3.6	0.6
7	4.3	2.4	4.2	2.2	4.2	2.0	4.1	1.6	4.0	1.3	4.0	1.1	3.9	0.9	3.8	0.7
8	4.5	2.6	4.5	2.4	4.4	2.2	4.3	1.8	4.3	1.5	4.2	1.3	4.1	1.0	4.1	0.8
9	4.7	2.8	4.7	2.6	4.6	2.4	4.5	1.9	4.5	1.6	4.4	1.4	4.3	1.1	4.2	0.9
10	4.9	3.0	4.8	2.7	4.8	2.5	4.7	2.0	4.60	1.7	4.6	1.5	4.5	1.2	4.4	1.0

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart 6

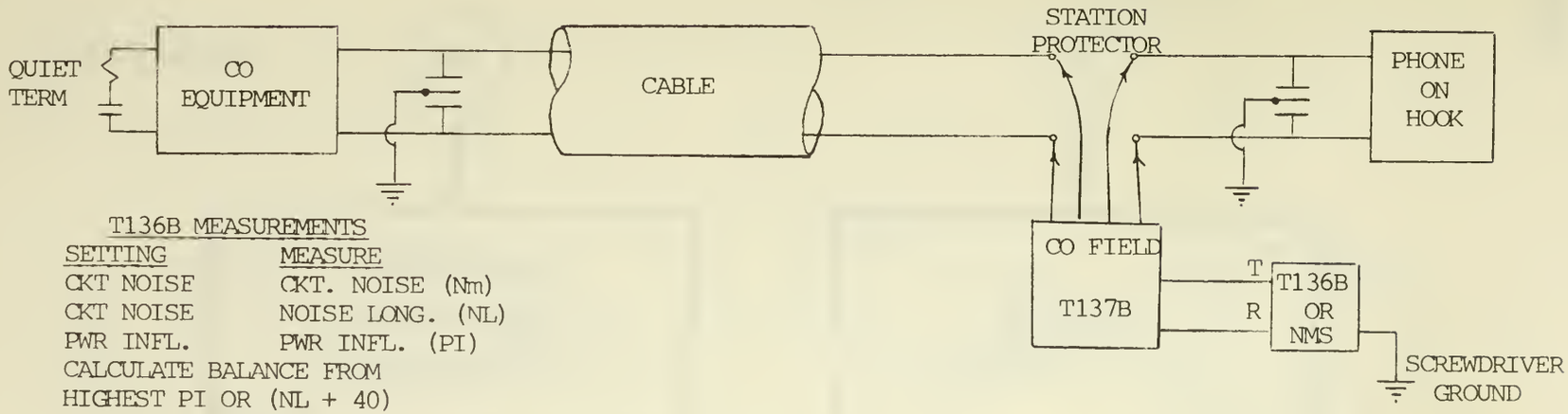
CO

Locate & Repair Problem

21

See REA TE&CM Section 451, Appendix C.

Go To Chart



T136B MEASUREMENTS

SETTING	MEASURE
CKT NOISE	CKT. NOISE (Nm)
CKT NOISE	NOISE LONG. (NL)
PWR INFL.	PWR INFL. (PI)

CALCULATE BALANCE FROM
HIGHEST PI OR (NL + 40)

NMS MEASUREMENTS

SETTINGS	MEASURE
CMSG 900 TERM MEAS.	Nm (CKT NOISE)
CMSG 900 TERM MEAS.	NOISE LONG. (NL)
CMSG Ng MEAS.	Ng (NOISE-TO-GROUND

CALCULATE BALANCE FROM HIGHEST PI:
(NL + 40) OR (Ng + 40)

*NOTE: MEASURE ONLY WHEN HIGH CKT NOISE IS FOUND ON MEAS. NO. 2.

T137B SETTINGS

	MEAS. NO. 1	MEAS. NO. 2	*MEAS. NO. 3
TERM:	OFF	OFF	OFF
LONG CURRENT:	OFF FOR CKT NOISE ON FOR NOISE LONG.	OFF FOR CKT NOISE ON FOR NOISE LONG.	OFF FOR CKT NOISE
DIAL-MEAS: FUNCTION:	MEAS. POSITION 1	MEAS. POSITION 2	MEAS. POSITION 6

ISOLATION MEASUREMENT AT SUBSCRIBER END
FIGURE 3

Chart *7

SUB

*

See REA TE&CM Section 451.1.

Isolation Measurement Subscriber End

Test configuration shown on Figure 3, Page 53N.

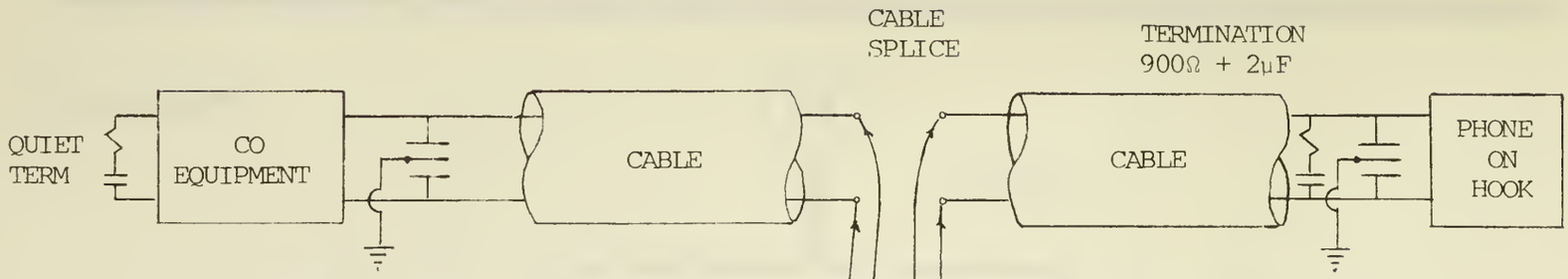
Problem in Subscriber Equipment

Problem in Cable?

Go To Chart (6)

(8)

*Measurements may be completed with Loop Checking equipment.



NMS MEASUREMENTS

	SETTINGS	MEASURE
CMSG	900 TERM MEAS.	Nm(CKT NOISE)
CMSG	900 TERM MEAS.	NOISE LONG. (NL)
CMSG	Ng MEAS.	Ng (NOISE-TO-GROUND)

CALCULATE BALANCE FROM HIGHEST PI:
(NL + 40) OR (Ng + 40).

T136B MEASUREMENTS

SETTINGS	MEASURE
CKT NOISE	CKT NOISE (Nm)
CKT NOISE	NOISE LONG. (NL)
PWR. INFL.	PWR. INFL. (PI)

CALCULATE BALANCE FROM
HIGHEST PI OR (NL + 40)

T137B SETTINGS

	MEAS. NO. 1	MEAS. NO. 2.
TERM:	OFF	OFF
LONG. CURRENT:	OFF FOR CKT NOISE ON FOR NOISE LONG.	OFF FOR CKT NOISE ON FOR NOISE LONG.
DIAL-MEAS: FUNCTION:	MEAS. POSITION 1	MEAS. POSITION 2

ISOLATION MEASUREMENT ALONG CABLE
FIGURE 4

Chart *8

See REA TE&CM Section 451.1.

Isolation Measurements Along Cable Until Problem is Found.

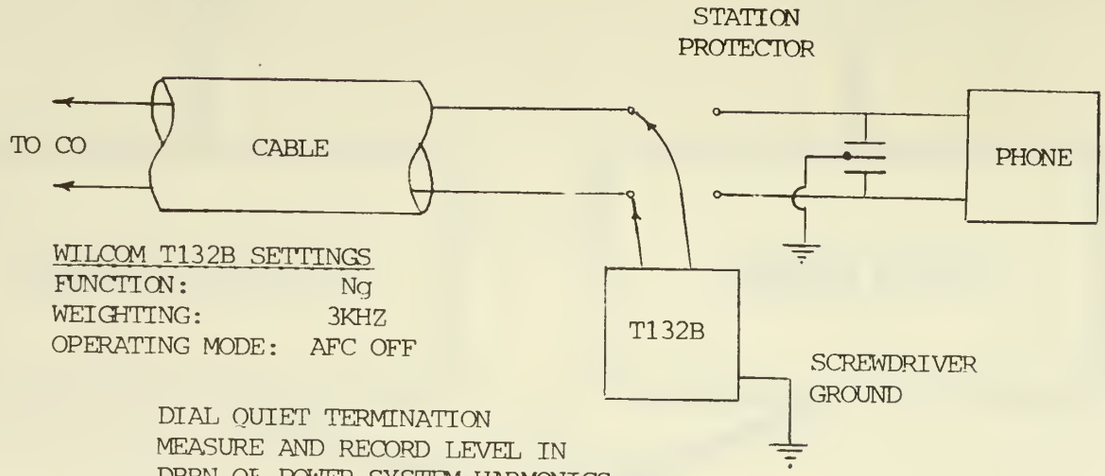
Test configuration shown on Figure 4, Page 53 P.

See REA TE&CM Section 451.8.

Repair

Go To Chart (21)

*Measurements may be completed with Loop Checking equipment.



WILCOM T132B SETTINGS
FUNCTION: Ng
WEIGHTING: 3KHZ
OPERATING MODE: AFC OFF

DIAL QUIET TERMINATION
MEASURE AND RECORD LEVEL IN
DBRN OF POWER SYSTEM HARMONICS
1 THROUGH 47 (60 TO 2820 HZ).

HARMONIC ANALYSIS OF POWER INFLUENCE
FIGURE 5

Chart 9

SUB

See REA TE&CM Section 452.1.

NOTE: If Spectrum Analyzer is not available go to Chart 10.

Measure Power Influence Harmonics and Analyze

Test configuration shown on Figure 5, Page 53R.

Shield Problem

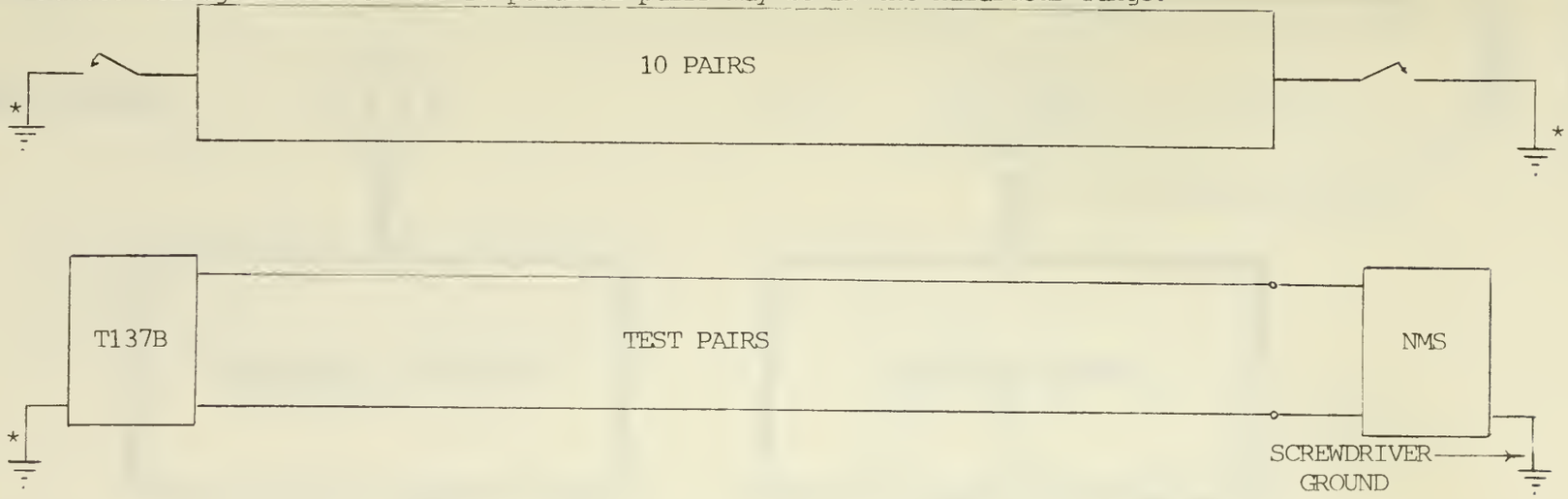
Shield Good

Go To Chart (10)

(19)

USE CAUTION

Induced voltage levels on the 10 parallel pairs may be in the hazardous range.



1. MEASURE Ng WITH 10-PAIRS UNGROUNDED.
2. MEASURE Ng WITH 10-PAIRS GROUNDED.
3. CALCULATE MEASURED DIFFERENCE - MEAS. 1 MINUS MEAS. 2.
4. DETERMINE SHIELD QUALITY FROM APPROPRIATE TABLE:

	5 mil CU 8 mil Al, 7 mil 194	10 mil CU	6 mil CCS, 6 mil 194
24 GA.	TABLE II, PAGE 53L	TABLE V, PAGE 54I	TABLE VIII, PAGE 540
22 GA.	TABLE III, PAGE 54C	TABLE VI, PAGE 54K	TABLE IX, PAGE 54Q
19 GA.	TABLE IV, PAGE 54E	TABLE VII, PAGE 54M	TABLE X, PAGE 54S

CU-COPPER AL-ALUMINUM CCS-COPPER CLAD STELL 194-ALLOY 194

* GROUNDS TO MGN.

T137B SETTINGS
TERM: ON
LONG. CURRENT: OFF
DIAL-MEAS: MEAS.
FUNCTION: POSITION 5
CONNECT TEST PAIR TO FIELD TERMINALS.

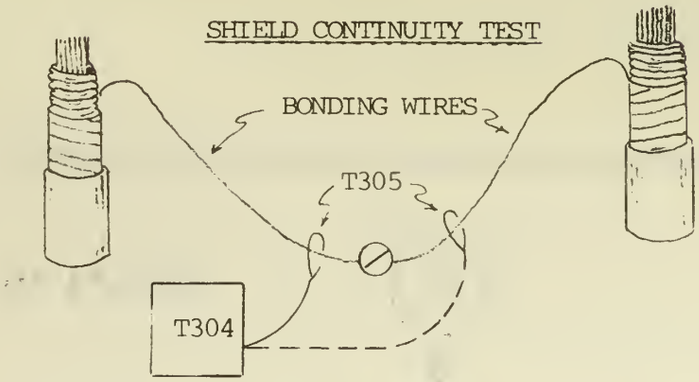
NMS MEASUREMENTS
SETTINGS MEASURE
C-MSG Ng MEAS. Ng

SHIELD MATERIALS
CU Copper
AL Aluminum
CCS Copper Clad Steel
194 Alloy 194

SHIELD CONTINUITY TEST
FIGURE 6

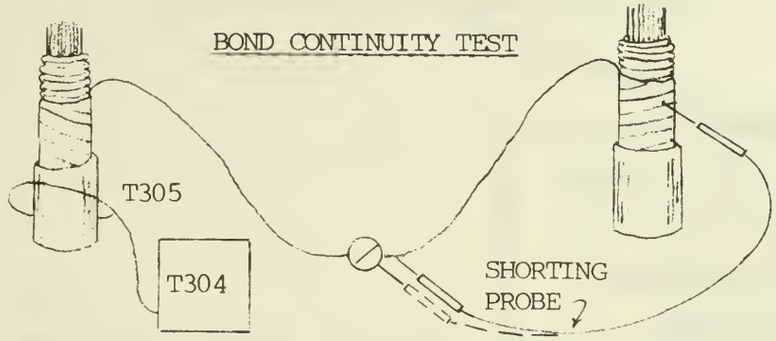
Chart 10

See REA TE&CM Section 451.2.
Test Continuity of Sections With One Size & Gauge
Test configuration shown on Figure 6, Page 53T.
Shield Problem
Shield Good
11
13
Go To Chart



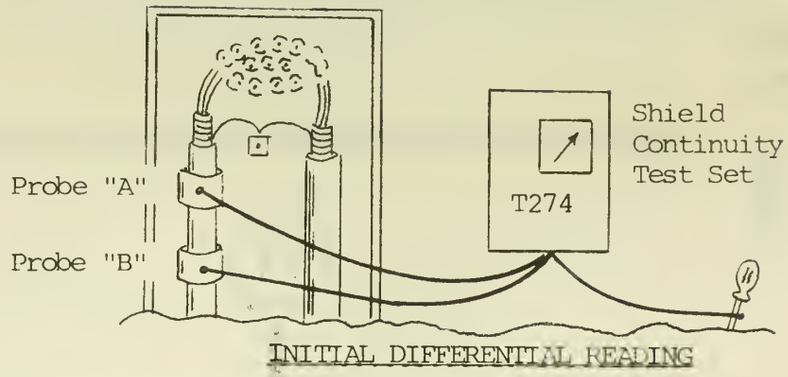
1. READ & RECORD CURRENT IN EACH BONDING WIRE AT EACH SPLICE.
2. CURRENT WILL REDUCE TO NEAR ZERO IN VICINITY OF OPEN SHIELD.
3. SEE REA TE&CM 451.2 FOR COMPLETE DETAILS.

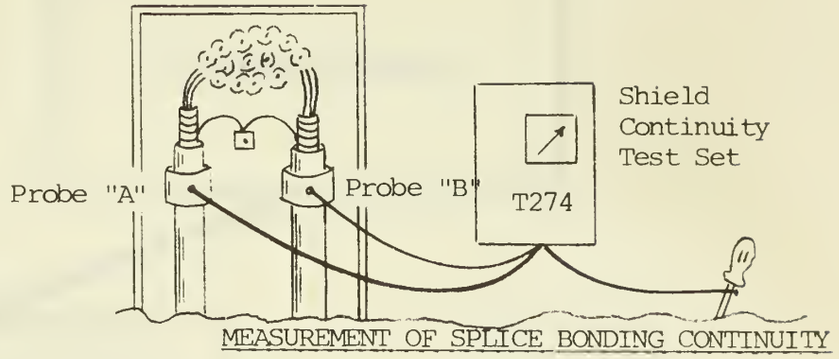
FIGURE 7A



1. READ CURRENT WITHOUT SHORTING PROBE
2. READ CURRENT WITH BOND WIRE BYPASSED BY PROBE
3. IF 2 IS 1.06 TIMES OR MORE GREATER THAN 1 BOND IS DEFECTIVE

FIGURE 7B



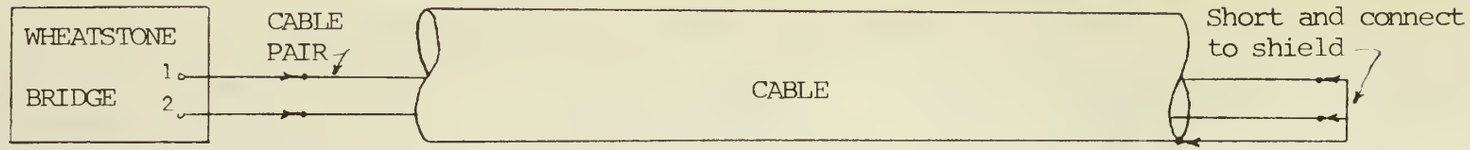


1. IF MEASUREMENT IS MORE THAN 2 DB GREATER THAN DIFFERENTIAL READING, BOND IS DEFECTIVE.
2. SEE REA TE&CM 451.2 FOR COMPLETE DETAILS.

SHIELD SPLICE CONTINUITY TEST
FIGURE 7C

Chart 11

See REA TE&CM Section 451.2.
Measure Shield Current Test for Bonding Problem
Test configuration shown on Figure 7, Page 53V.
Shield Problem
Shield Good
12
13
Go To Chart



1. Measure loop resistance R_1.

2. Measure loop resistance R_2.
3. Calculate shield resistance.

$$\text{Shield Resistance} = R_2 - \frac{R_1}{4}$$

WHEATSTONE BRIDGE MEASUREMENT OF SHIELD CONTINUITY
FIGURE 8

Chart 12

Test configuration for Wheatstone Bridge measurement shown on Figure 8, Page 54A.

Locate & Repair Problem

Shield in All Sections Good → 9

More Sections to Test → 10 → 11

More Splices in Section to Test → Go To Chart 11

TABLE III

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	22 GAUGE SHIELDS: 5mil CU, 8mil Al & 7mil 194															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	0.9	0.2	0.9	0.1	0.9	0.1	0.9	0.1	0.8	0.1	0.8	0.1	0.8	-	0.8	-
2	2.2	0.7	2.1	0.6	2.1	0.5	2.0	0.4	2.0	0.3	2.0	0.2	1.9	0.2	1.9	0.1
3	3.3	1.2	3.2	1.1	3.2	1.0	3.1	0.7	3.0	0.5	3.0	0.5	2.9	0.3	2.9	0.3
4	4.1	1.8	4.1	1.5	4.0	1.4	3.9	1.0	3.8	0.8	3.8	0.7	3.7	0.5	3.6	0.4
5	4.8	2.2	4.7	1.9	4.7	1.7	4.6	1.3	4.5	1.0	4.4	0.9	4.3	0.7	4.3	0.6
6	5.4	2.6	5.3	2.3	5.2	2.1	5.1	1.6	5.0	1.2	5.0	1.1	4.9	0.8	4.8	0.7
7	5.8	2.9	5.7	2.6	5.7	2.3	5.6	1.8	5.4	1.4	5.4	1.3	5.3	1.0	5.2	0.8
8	6.2	3.2	6.1	2.8	6.1	2.6	5.9	2.0	5.8	1.6	5.8	1.4	5.6	1.1	5.6	0.9
9	6.5	3.4	6.4	3.1	6.4	2.8	6.2	2.2	6.1	1.7	6.1	1.6	5.9	1.2	5.9	1.0
10	6.8	3.7	6.7	3.3	6.6	3.0	6.5	2.3	6.4	1.9	6.3	1.7	6.2	1.3	6.1	1.1

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart 13

Is this the Last Splice or Section
Shield in All Sections Good
9
More Sections to Test
10
11
More Splices in Section to Test
Go To Chart
11

TABLE IV

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	19 GAUGE SHIELDS: 5mil CU, 8mil Al & 7mil 194															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	1.0	0.2	1.0	0.1	1.0	0.1	0.9	0.1	0.9	0.1	0.9	-	0.9	-	0.9	-
2	2.5	0.7	2.5	0.6	2.5	0.5	2.4	0.3	2.3	0.3	2.3	0.2	2.2	0.2	2.2	0.1
3	4.0	1.3	3.9	1.1	3.9	1.0	3.7	0.6	3.7	0.5	3.6	0.5	3.5	0.3	3.5	0.3
4	5.2	1.9	5.1	1.7	5.1	1.4	4.9	1.0	4.8	0.8	4.8	0.7	4.7	0.5	4.6	0.4
5	6.2	2.5	6.1	2.1	6.1	1.9	5.9	1.3	5.8	1.1	5.7	0.9	5.6	0.7	5.6	0.6
6	7.0	2.9	6.9	2.5	6.9	2.2	6.7	1.5	6.6	1.3	6.5	1.1	6.4	0.8	6.3	0.7
7	7.7	3.4	7.6	2.9	7.6	2.6	7.3	1.8	7.3	1.5	7.2	1.3	7.1	1.0	7.0	0.9
8	8.3	3.7	8.2	3.2	8.1	2.9	7.9	2.0	7.8	1.7	7.8	1.5	7.6	1.1	7.6	1.0
9	8.8	4.0	8.7	3.5	8.7	3.1	8.4	2.2	8.3	1.9	8.3	1.6	8.1	1.2	8.1	1.0
10	9.3	4.3	9.2	3.8	9.1	3.4	8.9	2.4	8.8	2.0	8.7	1.8	8.5	1.4	8.5	1.2

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

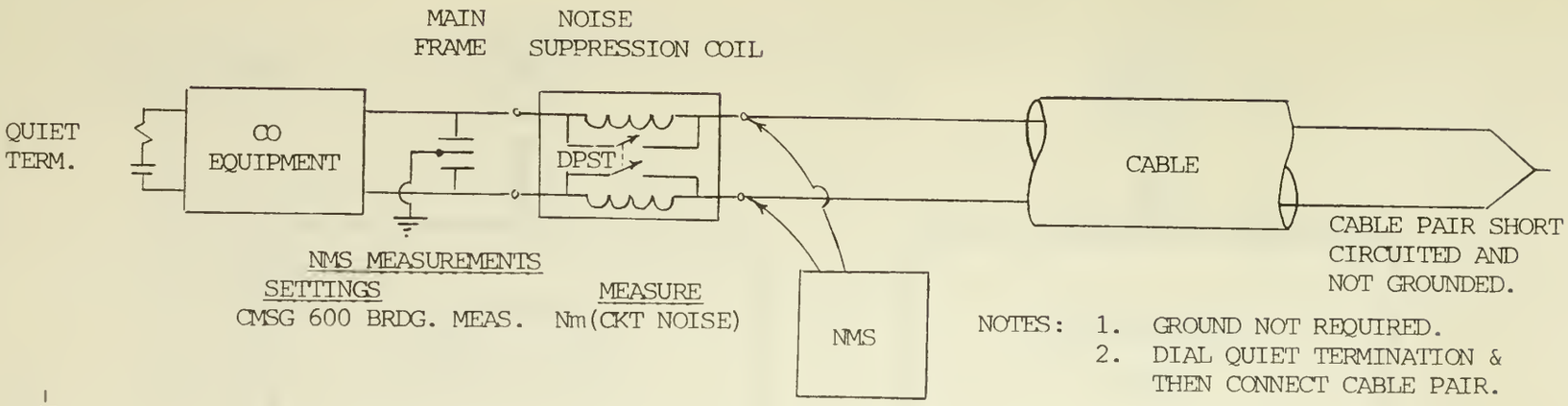
2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart 14

See REA TE&CM Section 451.
SUB
Test configuration shown on Figure 1, Page 53B.
Measure Power Influence 3Khz Flat Weighting
Less Than 105 dBrn
Between 105 & 126 dBrn
Greater Than 126 dBrn
Go To Chart
9
15
17



1. MEASURE CKT NOISE WITH COIL REMOVED FROM CKT. (SWITCH CLOSED)
2. MEASURE CKT NOISE WITH COIL IN CKT. (SWITCH OPEN)
3. LARGE REDUCTION OF CKT NOISE (GREATER THAN 15 DBRNC) INDICATES PROBABLE SATURATION.

SATURATION TEST
FIGURE 9

Chart 15

See REA TE&CM Section 451.8.
CO
Test configuration shown on Figure 9, Page 54G.
Test for Possible Equipment Saturation
Saturation Present
16
No Saturation
17
Go To Chart

TABLE V

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	24 GAUGE SHIELDS: 10mil CU															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	0.8	0.1	0.8	0.1	0.8	0.1	0.8	-	0.7	-	0.7	-	0.7	-	0.7	-
2	1.8	0.3	1.8	0.3	1.8	0.2	1.7	0.2	1.7	0.1	1.6	0.1	1.6	0.1	1.6	0.1
3	2.6	0.6	2.5	0.5	2.5	0.4	2.5	0.3	2.4	0.2	2.4	0.2	2.3	0.1	2.3	0.1
4	3.2	0.8	3.1	0.7	3.1	0.6	3.0	0.4	3.0	0.3	2.9	0.3	2.9	0.2	2.8	0.2
5	3.6	1.0	3.6	0.9	3.6	0.8	3.5	0.6	3.4	0.4	3.4	0.4	3.3	0.3	3.2	0.2
6	4.0	1.2	4.0	1.1	3.9	1.0	3.8	0.7	3.8	0.5	3.7	0.5	3.6	0.3	3.6	0.3
7	4.3	1.4	4.2	1.2	4.2	1.1	4.1	0.8	4.0	0.6	4.0	0.5	3.9	0.4	3.8	0.3
8	4.5	1.5	4.5	1.4	4.4	1.2	4.3	0.9	4.3	0.7	4.2	0.6	4.1	0.4	4.1	0.4
9	4.7	1.7	4.7	1.5	4.6	1.3	4.5	1.0	4.5	0.8	4.4	0.7	4.3	0.5	4.2	0.4
10	4.9	1.8	4.8	1.6	4.8	1.4	4.7	1.1	4.6	0.8	4.6	0.7	4.5	0.5	4.4	0.4

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart 16

CO

Mitigate Saturation Effects

See REA TE&CM Sections 451.4 and 451.5.

Go To Chart 17

TABLE VI

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	22 GAUGE SHIELDS: 10mil CU															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	0.9	0.1	0.9	0.1	0.9	0.1	0.9	-	0.8	-	0.8	-	0.8	-	0.8	-
2	2.2	0.4	2.1	0.3	2.1	0.2	2.0	0.2	2.0	0.1	2.0	0.1	1.9	0.1	1.9	0.1
3	3.3	0.7	3.2	0.6	3.2	0.5	3.1	0.3	3.0	0.2	3.0	0.2	2.9	0.1	2.9	0.1
4	4.1	1.0	4.1	0.8	4.0	0.7	3.9	0.5	3.8	0.4	3.8	0.3	3.7	0.2	3.6	0.2
5	4.8	1.2	4.7	1.0	4.7	0.9	4.6	0.6	4.5	0.5	4.4	0.4	4.3	0.3	4.3	0.2
6	5.4	1.5	5.3	1.2	5.2	1.1	5.1	0.8	5.0	0.6	5.0	0.5	4.9	0.4	4.8	0.3
7	5.8	1.7	5.7	1.4	5.7	1.2	5.6	0.9	5.4	0.7	5.4	0.6	5.3	0.4	5.2	0.3
8	6.2	1.8	6.1	1.6	6.1	1.4	5.9	1.0	5.8	0.7	5.8	0.7	5.6	0.5	5.6	0.4
9	6.5	2.0	6.4	1.7	6.4	1.5	6.2	1.1	6.1	0.8	6.1	0.7	5.9	0.5	5.9	0.4
10	6.8	2.2	6.7	1.9	6.6	1.6	6.5	1.2	6.4	0.9	6.3	0.8	6.2	0.6	6.1	0.5

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart 17

SUB

See REA TE&CM Section 452.2.

Measure Power Influence Harmonics and Analyze

Test configuration shown on Figure 5, Page 53R.

See REA TE&CM Sections 452 and 452.2.

Complete Additional Tests, as Required, to Verify Problem(s)

Go To Chart (18)

TABLE VII

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	19 GAUGE SHIELDS: 10mil CU															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	1.0	0.1	1.0	0.1	1.0	0.1	0.9	-	0.9	-	0.9	-	0.9	-	0.9	-
2	2.5	0.4	2.5	0.3	2.5	0.2	2.4	0.1	2.3	0.1	2.3	0.1	2.2	0.1	2.2	0.1
3	4.0	0.7	3.9	0.6	3.9	0.5	3.7	0.3	3.7	0.2	3.6	0.2	3.5	0.1	3.5	0.1
4	5.2	1.1	5.1	0.9	5.1	0.7	4.9	0.4	4.8	0.4	4.8	0.3	4.7	0.2	4.6	0.2
5	6.2	1.4	6.1	1.1	6.1	1.0	5.9	0.6	5.8	0.5	5.7	0.4	5.6	0.3	5.6	0.2
6	7.0	1.6	6.9	1.4	6.9	1.2	6.7	0.7	6.6	0.6	6.5	0.5	6.4	0.4	6.3	0.3
7	7.7	1.9	7.6	1.6	7.6	1.4	7.3	0.8	7.3	0.7	7.2	0.6	7.1	0.4	7.0	0.4
8	8.3	2.1	8.2	1.8	8.1	1.5	7.9	1.0	7.8	0.8	7.8	0.7	7.6	0.5	7.6	0.4
9	8.8	2.3	8.7	2.0	8.7	1.7	8.4	1.1	8.3	0.9	8.3	0.7	8.1	0.5	8.1	0.5
10	9.3	2.5	9.2	2.1	9.1	1.8	8.9	1.2	8.8	1.0	8.7	0.8	8.5	0.6	8.5	0.5

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart 18

See REA TE&CM Section 451.

Contact Power Company for Coordination

Mitigate

21

Go To Chart

TABLE VIII

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	24 GAUGE SHIELDS: 6mil CCS & 6mil 194															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	0.8	0.2	0.8	0.2	0.8	0.2	0.8	0.1	0.8	0.1	0.7	0.1	0.7	0.1	0.7	0.1
2	1.8	0.8	1.8	0.7	1.8	0.7	1.7	0.5	1.7	0.4	1.6	0.3	1.6	0.3	1.6	0.2
3	2.6	1.4	2.5	1.3	2.5	1.2	2.5	0.9	2.4	0.8	2.4	0.7	2.3	0.5	2.3	0.4
4	3.2	1.9	3.1	1.7	3.1	1.6	3.0	1.3	3.0	1.1	2.9	0.9	2.9	0.7	2.8	0.6
5	3.6	2.3	3.6	2.1	3.6	2.0	3.5	1.6	3.4	1.4	3.4	1.2	3.3	1.0	3.2	0.8
6	4.0	2.7	4.0	2.5	3.9	2.3	3.8	1.9	3.8	1.6	3.7	1.4	3.6	1.1	3.6	0.9
7	4.3	3.0	4.2	2.8	4.2	2.6	4.1	2.1	4.0	1.8	4.0	1.6	3.9	1.3	3.8	1.1
8	4.5	3.2	4.5	3.0	4.4	2.8	4.3	2.3	4.3	2.0	4.2	1.8	4.1	1.4	4.1	1.2
9	4.7	3.4	4.7	3.2	4.6	3.0	4.5	2.5	4.5	2.1	4.4	1.9	4.3	1.6	4.2	1.3
10	4.9	3.6	4.8	3.4	4.8	3.2	4.7	2.60	4.6	2.3	4.6	2.0	4.5	1.7	4.4	1.4

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart *19

SUB

*

See REA TE&CM Section 451.

Measure Circuit Noise

Test configuration shown on Figure 1, Page 53B.

Less Than 20 dBrnc

Greater Than 20 dBrnc

Go To Chart (21)

(20)

*Measurements may be completed with Loop Checking equipment.

TABLE IX

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	22 GAUGE SHIELDS: 6mil CCS & 6mil 194															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	0.9	0.2	0.9	0.2	0.9	0.2	0.9	0.1	0.8	0.1	0.8	0.1	0.8	0.1	0.8	0.1
2	2.2	0.9	2.1	0.8	2.1	0.7	2.0	0.5	2.0	0.4	2.0	0.4	1.9	0.3	1.9	0.2
3	3.3	1.6	3.2	1.4	3.2	1.3	3.1	1.0	3.0	0.8	3.0	0.7	2.9	0.5	2.9	0.4
4	4.1	2.2	4.1	2.0	4.0	1.8	3.9	1.4	3.8	1.1	3.8	1.0	3.7	0.8	3.6	0.7
5	4.8	2.8	4.7	2.5	4.7	2.2	4.6	1.8	4.5	1.4	4.4	1.3	4.3	1.0	4.3	0.9
6	5.4	3.2	5.3	2.9	5.2	2.6	5.1	2.1	5.0	1.7	5.0	1.6	4.9	1.2	4.8	1.0
7	5.8	3.6	5.7	3.3	5.7	2.9	5.6	2.4	5.4	2.0	5.4	1.8	5.3	1.4	5.2	1.2
8	6.2	3.9	6.1	3.6	6.1	3.2	5.9	2.7	5.8	2.2	5.8	2.0	5.6	1.6	5.6	1.4
9	6.5	4.2	6.4	3.9	6.4	3.5	6.2	2.9	6.1	2.4	6.1	2.2	5.9	1.7	5.9	1.5
10	6.8	4.5	6.7	4.1	6.6	3.7	6.5	3.1	6.4	2.5	6.3	2.3	6.2	1.9	6.1	1.6

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

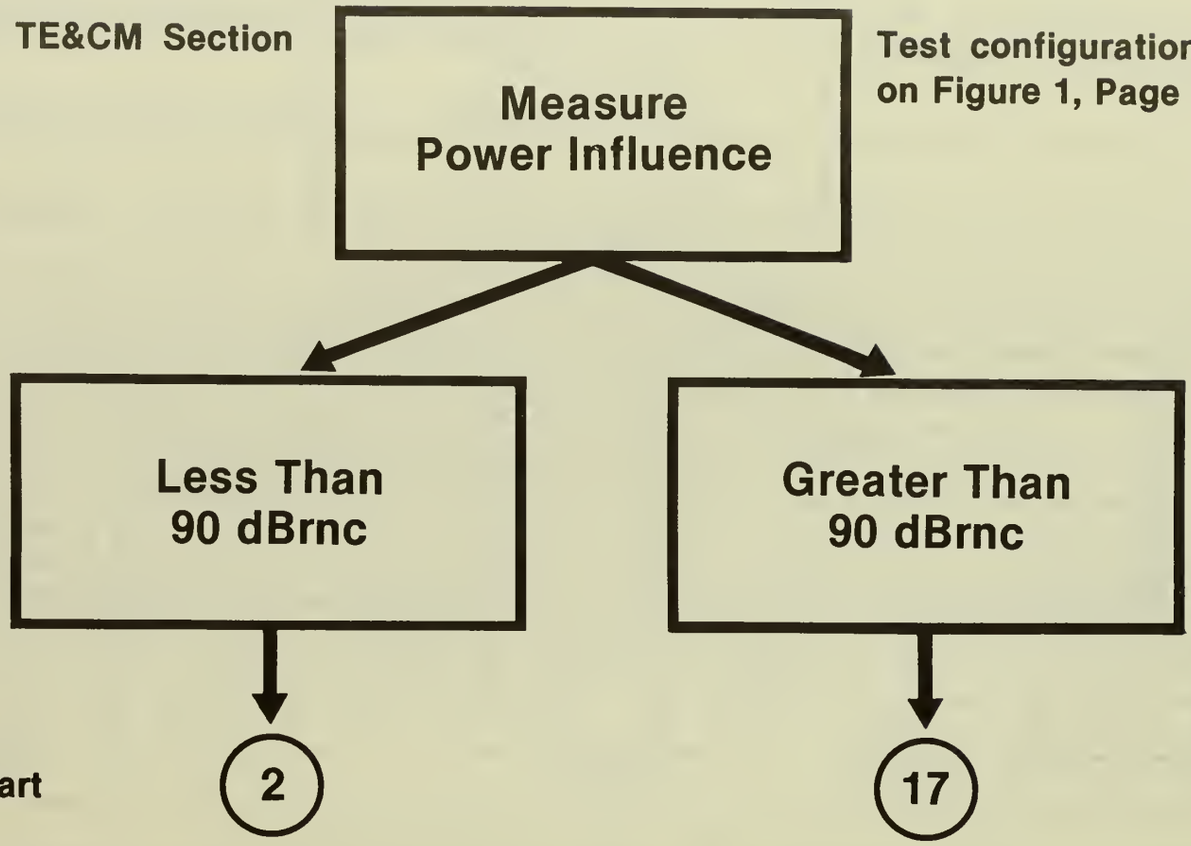
Chart *20

*

SUB

See REA TE&CM Section 451.

Test configuration shown on Figure 1, Page 53B.



Go To Chart (2)

Go To Chart (17)

*Measurements may be completed with Loop Checking equipment.

TABLE X

For identification of an Open Shield (Based on 540 Hz)

Length-Kf.	19½ GAUGE SHIELDS: 6mil CCS & 6mil 194															
	12 Pr.		18 Pr.		25 Pr.		50 Pr.		75 Pr.		100 Pr.		150 Pr.		200 Pr.	
	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.	10 Pr.	Diff.
1	1.0	0.2	1.0	0.2	1.0	0.2	0.9	0.1	0.9	0.1	0.9	0.1	0.9	0.1	0.9	-
2	2.5	0.9	2.5	0.8	2.5	0.7	2.4	0.5	2.3	0.4	2.3	0.3	2.2	0.3	2.2	0.2
3	4.0	1.8	3.9	1.5	3.9	1.3	3.7	0.9	3.7	0.8	3.6	0.7	3.5	0.5	3.5	0.5
4	5.2	2.5	5.1	2.2	5.1	1.9	4.9	1.4	4.8	1.2	4.8	1.0	4.7	0.8	4.6	0.7
5	6.2	3.2	6.1	2.8	6.1	2.5	5.9	1.8	5.8	1.5	5.7	1.3	5.6	1.0	5.6	0.9
6	7.0	3.7	6.9	3.3	6.9	3.0	6.7	2.1	6.6	1.8	6.5	1.6	6.4	1.2	6.3	1.1
7	7.7	4.2	7.6	3.7	7.6	3.4	7.3	2.5	7.3	2.1	7.2	1.9	7.1	1.5	7.0	1.3
8	8.3	4.7	8.2	4.1	8.1	3.8	7.9	2.7	7.8	2.4	7.8	2.1	7.6	1.6	7.6	1.5
9	8.8	5.00	8.7	4.5	8.7	4.1	8.4	3.0	8.3	2.6	8.3	2.3	8.1	1.8	8.1	1.6
10	9.3	5.4	9.2	4.8	9.1	4.4	8.9	3.2	8.8	2.8	8.7	2.5	8.5	2.0	8.5	1.8

1. If measured difference is nearly equal to (less than 50% greater) or less than the calculated difference, the shield can be considered acceptable.

2. If measured difference is more than 50% greater than the calculated difference the shield is probably partially open.

3. If measured difference is nearly equal to or greater than the value in the "10 Pr." column, the shield can be considered completely open.

NOTE: Use for Air Core, Filled, and Foam Insulated Filled Cables.

Chart *21

SUB

Test configuration shown on Figure 1, Page 53B.

*

Measure Power Influence & Circuit Noise to Confirm Mitigation

See REA TE&CM Section 451.

*Measurements may be completed with Loop Checking equipment.

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Rural Electrification Administration
Telecommunications Engineering and Construction Manual

Section 452
Issue No. 1
December 1980

SPECIALIZED TELEPHONE NOISE MEASUREMENTS AND INVESTIGATION

DEPOSITORY

DEC 31 1980

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

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1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to provide an understanding of specialized noise measurements in the telecommunications network. Specialized noise measurements are defined as those which are observed as a continuation of an initial noise investigation undertaken by the telephone company craftspeople which has not provided a solution to the problem. As in TE&CM Section 451, the discussion will be primarily directed to interference from harmonics of 60 Hertz power lines.

1.2 Section 451 provided information on techniques for measurement, analysis, isolation and solution of noise problems in the telephone plant by telephone company craftspeople. If, after completing those techniques, it is determined that the telephone plant has high balance, shields are continuous, noise is not originating in the telephone system, etc., it can be assumed the noise probably is the result of some abnormal condition in the power system.

1.3 The investigation at this stage has turned from studying potential problem areas in the telephone system toward a search for problem areas in the power system. While the power company could be contacted at this point there are some additional measurements which can be completed by telephone company personnel. In many situations the power system problem areas can be identified and sometimes located through completion of these measurements. This information can help make the initial contact with the power company more productive.

1.4 Performance of a power system may be analyzed by studying the voltage or current waveform. Since the majority of telephone service today is provided via shielded cable only the power system current waveform will be discussed. This is due to the induced noise in cable being the result of magnetic coupling as discussed in TE&CM Section 451.

2. POWER LINE UNBALANCE CURRENT

2.1 As discussed in Paragraph 7 of TE&CM Section 451, earth return currents of power system harmonics are the source of a high percentage of noise problems in telephone systems. Odd-triple (Zero Sequence, 3rd, 9th, 15th, etc.) harmonics are of major concern since odd-triple currents in each phase conductor are in phase (at the same phase angle). Earth return current is the vector sum of the currents in the phase conductors. When currents are in phase, as with an odd-triple harmonic, the resultant contribution to earth return current is merely the arithmetic sum of the in phase currents. Unbalanced conditions will only make this condition more severe because the vector sum resolution of unequal <u>non</u> odd-triple harmonics contribute to the ground return current where on a balanced system they cancel and are not part of earth return.

2.2 Fundamental frequency phase currents may be shown by a vector (See Figure 1). The current in each phase is thus:

$$I_A\ 0^\circ = I_A\ (\cos 0^\circ + j \sin 0^\circ) = 1I_A + j\ 0I_A$$

$$I_B\ 120^\circ = I_B\ (\cos 120^\circ + j \sin 120^\circ) = -.5I_B + j.87I_B$$

$$I_C\ 240^\circ = I_C\ (\cos 240^\circ + j \sin 240^\circ) = -.5I_C - j.87I_B$$

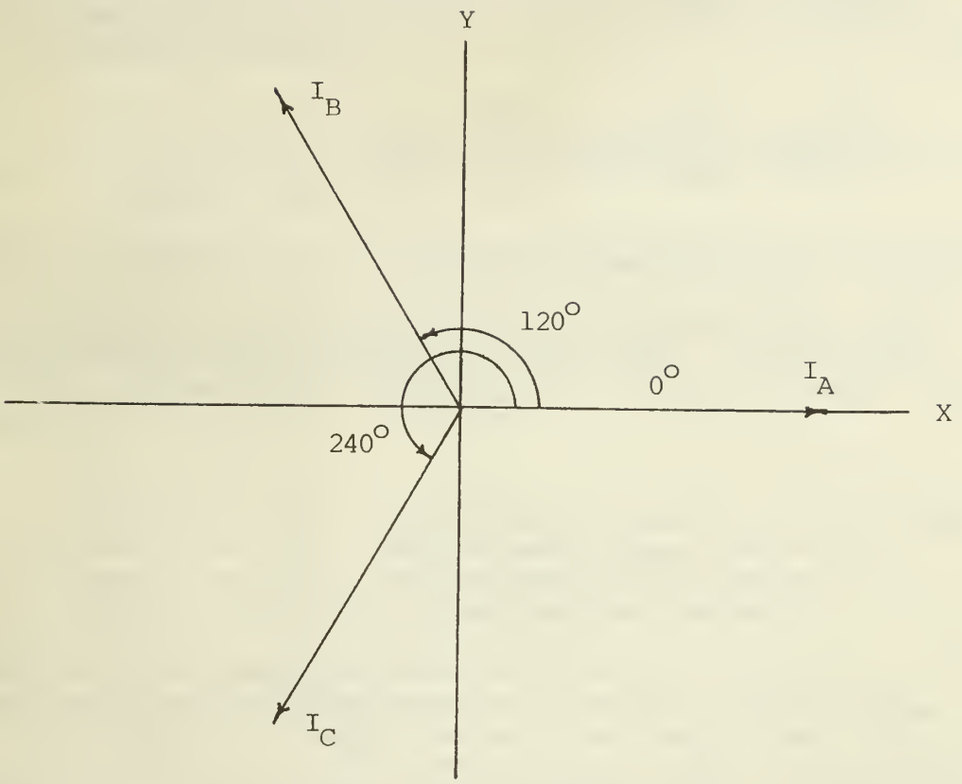


FIGURE 1: PHASE CURRENTS IN THREE-PHASE POWER SYSTEM

2.2.1 Where phase current magnitudes are the same ($I_A = I_B = I_C$) there is no unbalance current and there is no contribution to earth return current. Assuming a 40 ampere current in each phase:

$$\begin{aligned} 1\ (40) + j\ 0(40) &= \quad 40 + j\ 0 \\ -.5\ (40) + j\ .87\ (40) &= -20 + j\ 34.8 \\ -.5\ (40) - j\ .87\ (40) &= \underline{-20 - j\ 34.8} \\ &= \quad 0 + j\ 0 \text{ Ampere Unbalance} \end{aligned}$$

2.2.2 When magnitudes, $I_A \neq I_B \neq I_C$, the vector sum of the currents will not be zero and there will be an unbalance current which will return via the neutral conductor and earth. Assuming $I_A = 20$, $I_B = 80$, $I_C = 40$, Amperes.

$$\begin{aligned} 1\ (20) + j\ 0\ (20) &= \quad 20 + j\ 0 \\ -.5\ (80) + j\ .87\ (80) &= -40 + j\ 69.6 \\ -.5\ (40) - j\ .87\ (40) &= \underline{-20 - j\ 34.8} \\ &\quad -40 + j\ 34.8 \text{ Ampere Unbalance} \end{aligned}$$

Converting from rectangular to polar form = $53\ \underline{/139^\circ}$ Amperes Unbalance

2.2.3 The unbalance current remains the same regardless of which phase is carrying a given current. For example assume the same three phase currents shown in Paragraph 2.2.2, above but distributed among the phases thus, $I_A = 80$ $I_B = 40$ $I_C = 20$. Only the phase angle changes.

$$\begin{aligned} 1\ (80) + j\ 0\ (80) &= 80 + j\ 0 \\ -.5\ (40) + j\ .87\ (40) &= -20 + j\ 34.8 \\ -.5\ (20) + j\ .87\ (20) &= \underline{-10 - j\ 17.4} \\ & \quad 50 + j\ 17.4 \text{ Ampere Unbalance} \end{aligned}$$

Converting from rectangular to polar form = 53 $\angle 19^{\circ}$ Amperes Unbalance

2.3 There is the special case where two of the phase currents are of equal magnitude. The vectors can be oriented so that the j components will cancel out and the following equation will apply:

$$.5I_e + .5I_e - I_u = I_N$$

Where: I_e = The equal phase currents
I_u = The unequal phase current
I_N = The unbalance current that would flow in the neutral and earth path.

2.3.1 This equation is easier to use than the computation of the vector sum of the phase currents. It is reasonably accurate even when the two "equal" phase currents vary from each other by as much as twenty percent provided the "unequal" phase current is large in relation to the "equal" phase currents. For example, take a case where; $I_A = 40$, $I_B = 80$, and $I_C = 48$ amperes. .5 (40 + .5 (48) = 20 + 24 - 80 = 36 amperes.

2.3.2 The vector sum computation for the phase currents shown in Paragraph 2.3.1 is:

$$\begin{aligned} 1\ (40) + j\ 0\ (40) &= 40 + j\ 0 \\ -.5\ (80) + j\ .87\ (80) &= -40 + j\ 69.6 \\ -.5\ (48) - j\ .87\ (48) &= \underline{-24 - j\ 41.8} \\ & \quad -24 + j\ 27.8 \text{ Ampere Unbalance} \end{aligned}$$

Converting from rectangular to polar form = 37 $\angle 130^{\circ}$ Amperes Unbalance

2.4 Power line currents may be measured directly at any location. Power company personnel can measure current in each phase wire and the neutral wire with a clamp-on ammeter and compute the earth return current. This method is accurate but involves a lot of time and expense. As will be discussed later there are methods of determining the magnitude of earth return currents with a reasonable accuracy which are fast, inexpensive and do not require power company assistance.

3. MUTUAL IMPEDANCE

3.1 A simple explanation of magnetic induction is given in Paragraph 4 of TE&CM Section 451. It describes how a magnetic field produced by an ac current flowing in a power conductor will induce a longitudinal voltage in a nearby telephone conductor. The magnitude of this induced voltage may be determined for an unshielded telephone conductor by calculating the mutual impedance between the two conductors and multiplying this impedance by the earth return current.

3.1.1 Mutual impedance may be defined as the ratio of the induced open circuit voltage to ground in the telephone conductor per unit length to the unbalance current (earth return current) in the power system.

3.1.2 Mutual impedance provides a valuable tool for use during noise investigations. The expected power influence in an exposed telephone circuit can be calculated for comparison with recorded measured values. Other paralleling metallic conductors, including the telephone cable shield help "shield" cable pairs and reduce induced voltages. Shielding, therefore, should be considered in any calculations. Shielding and shield factors will be presented in Paragraph 4 of this TE&CM.

3.2 J. R. Carson of Bell Laboratories developed the equation for mutual impedance in 1926. E. D. Sunde[1] presented a simplified form of Carsons equation for mutual impedance between power and telephone. For separations between the two facilities normally found during noise investigations, Sunde's simplified equation is valid to within five percent. This is an acceptable accuracy for calculations discussed in this section. Sunde's simplified equation for close separation is:

$$Z_{12} = \frac{j\,\omega\mu_o}{4\pi}\left[2\ln\left(\frac{\sqrt{2}\,\delta}{g d_{12}}\right) + 1 - \frac{j\pi}{2} + \frac{4}{3\delta}(1+j)(h_1+h_2)\right]$$

Where: Z_{12} = Complex mutual impedance per unit length (ohms/meter)
ω = $2\pi f$ = angular frequency of inducing current (radians per second)
μ_o = $4\pi \times 10^{-7}$ = free space permeability (henry/meter)
g = $1.7811 = e^{\gamma}$
d_{12} = $\sqrt{(h_1 - h_2)^2 + x^2}$ = radial distance between conductors
X = horizontal separation between power and telephone lines
h_1 = height of power line above ground (negative if buried cable)
h_2 = height of telephone line above ground (negative if buried cable)
ρ = earth resistivity in meter-ohms
δ = skin depth in meters = $2\rho/\omega\mu_o$
γ = .5772 = Euler's Constant
In = Log_e

NOTE: X, h_1 and h_2 are in meters.

3.2.1 A complex impedance is made up of a real part and an imaginary part. Thus, the complex impedance (Z_{12}) is composed of a mutual resistance (R_{12}) and a mutual reactance (X_{12}). Therefore, $Z_{12} = R_{12} + jX_{12}$.

3.2.2 The equation shown in Paragraph 3.2 can be simplified by collecting its real and imaginary parts. This simplification is valuable for engineers when performing mutual impedance calculations. The real part of the equation is:

[1] E. D. Sunde, "Earth Conduction Effects in Transmission Systems", Dover Publications, N. Y. (1968).

$$R_{12} = \frac{\omega\mu_o}{4\pi}\left[\frac{\pi}{2} - \frac{4}{3\delta}(h_1 + h_2)\right]$$

and the imaginary part is:

$$X_{12} = \frac{\omega\mu_o}{4\pi}\left[2\text{In}\left(\frac{\sqrt{2\delta}}{gd_{12}}\right) + 1 + \frac{4}{3\delta}(h_1 + h_2)\right]$$

3.2.3 The results of computations in ohms/meter may be converted to ohms/kilofoot by multiplying by 304.8.

3.4 The equation in Paragraph 3.2.2 has been used to develop the curves in Figure 2 for determining the mutual impedance between the power and telephone system at the fundamental frequency (60 Hertz). To use the chart enter from the bottom scale following the vertical line from the separation of the conductors in feet to the point of intersection with the earth resistivity line of interest. Read the mutual impedance on the left hand scale of the chart along the horizontal line from the point of intersection.

3.4.1 Assuming there is a buried telephone cable beneath a power line and the separation between them is 44 feet in an area with 100 meter-ohms earth resistivity enter the Figure 2 at 44 foot point on the bottom scale and follow this vertical line to the point where it intersects the $\rho = 100$ line. Moving horizontally to the left scale, observe that the mutual impedance is about 0.098 ohms per kilofoot. If there is one ampere of 60 Hz earth return current in the power system there would be an open circuit 60 Hz voltage to ground of 0.098 volts per kilofoot of unshielded telephone conductor.

3.4.2 Where the average earth resistivity of an area is known and it is not close to one shown, the chart may be entered at the point $(d)/\sqrt{\rho}$ on the bottom scale. Follow the vertical line to the intersection with the $\rho = 1$ curve and read Zm of this point on the left scale of the chart.

3.5 The curves in Figure 3 are for determining the mutual impedance between power and telephone systems at a frequency of 540 Hertz. Application is identical to that for Figure 2 discussed in Paragraph 3.4, above.

3.6 The use of Figures 2 and 3 should cover most situations where calculations of mutual impedance between power and telephone systems are desired. There will be cases where harmonics other than the ninth (540 Hertz) are predominant and mutual impedances at these harmonics are desired. Figure 4 has been developed for these cases. Figure 4 provides the mutual impedance in ohms per Hertz. The chart is entered along the bottom horizontal scale at the point $(d) \times \sqrt{f}$ (d = conductor separation in feet and f = frequency in Hertz). Follow the vertical line to the point of intersection with earth resistivity of interest and read the mutual impedance for one Hertz on the left scale of the chart. Multiply this value by f to obtain the desired mutual impedance in ohms per kilofoot.

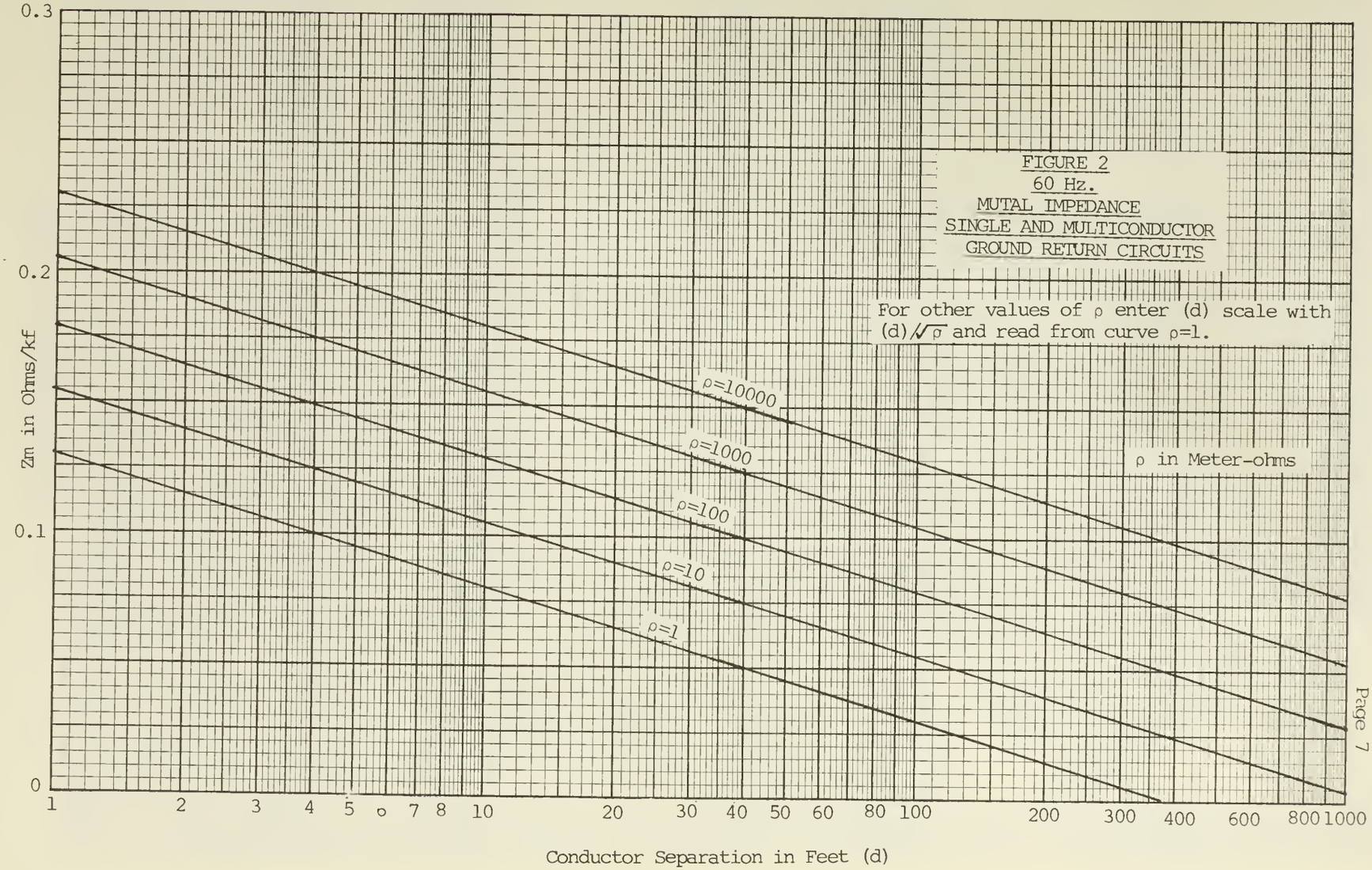


FIGURE 2
60 Hz.
MUTAL IMPEDANCE
SINGLE AND MULTICONDUCTOR
GROUND RETURN CIRCUITS
For other values of ρ enter (d) scale with (d)/√ρ and read from curve ρ=1.
ρ in Meter-ohms
ρ=10000
ρ=1000
ρ=100
ρ=10
ρ=1
Zm in Ohms/kf
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
10
20
30
40
50
60
80
100
200
300
400
600
800
1000
Conductor Separation in Feet (d)

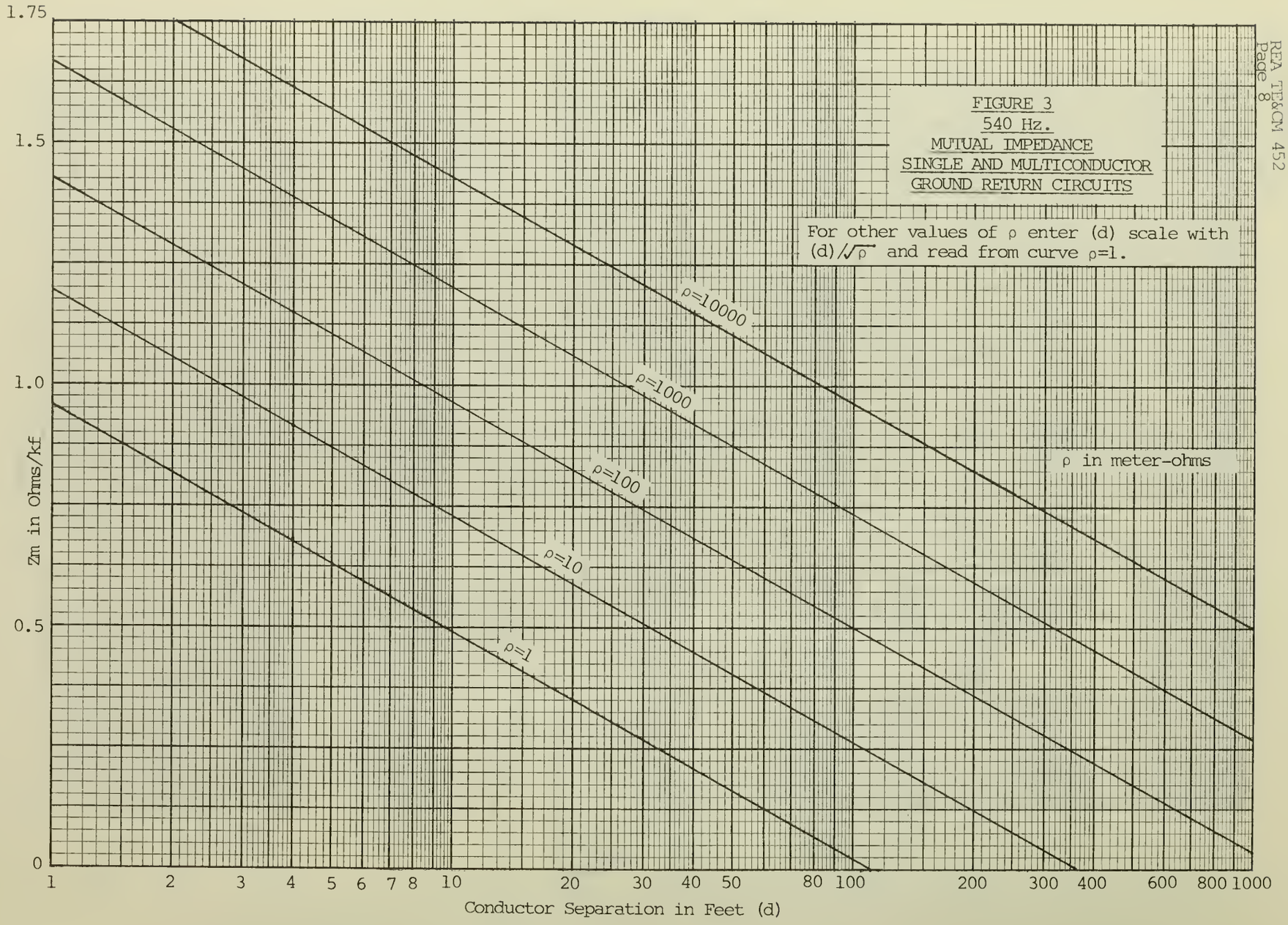


FIGURE 3
540 Hz.
MUTUAL IMPEDANCE
SINGLE AND MULTICONDUCTOR
GROUND RETURN CIRCUITS
For other values of ρ enter (d) scale with (d)/√ρ and read from curve ρ=1.
ρ in meter-ohms
ρ=10000
ρ=1000
ρ=100
ρ=10
ρ=1
Zm in Ohms/kf
1.75
1.5
1.0
0.5
0
1
2
3
4
5
6
7
8
10
20
30
40
50
80
100
200
300
400
600
800
1000
Conductor Separation in Feet (d)

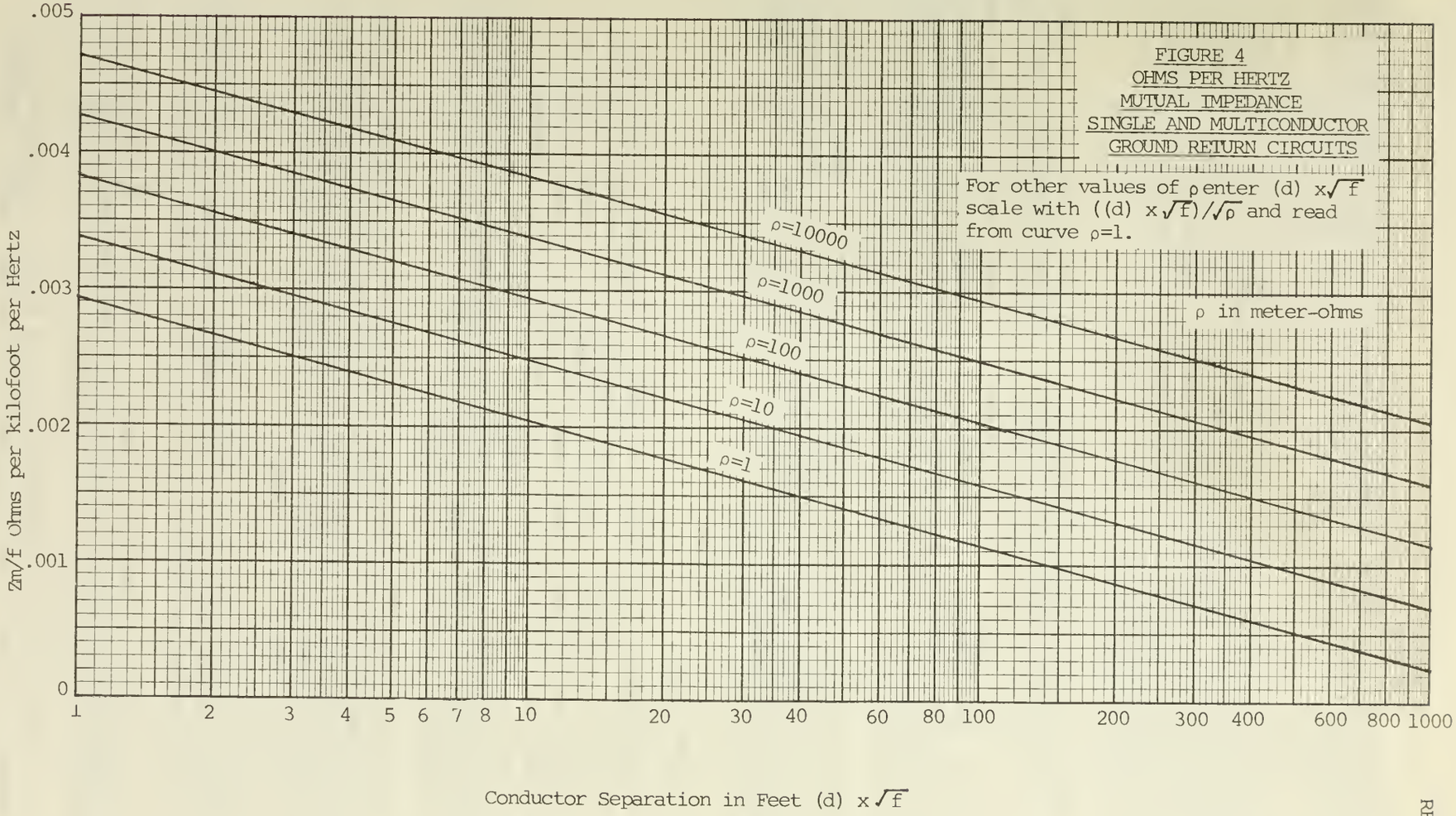


FIGURE 4
OHMS PER HERTZ
MUTUAL IMPEDANCE
SINGLE AND MULTICONDUCTOR
GROUND RETURN CIRCUITS
For other values of ρ enter (d) x√f scale with ((d) x√f)/√ρ and read from curve ρ=1.
ρ in meter-ohms
ρ=10000
ρ=1000
ρ=100
ρ=10
ρ=1
Zm/f Ohms per kilofoot per Hertz
.005
.004
.003
.002
.001
0
1
2
3
4
5
6
7
8
10
20
30
40
60
80
100
200
300
400
600
800
1000
Conductor Separation in Feet (d) x√f

3.6.1 Assume the predominant harmonic along a power line proves to be the fifteenth (900 Hertz). The separation between power and telephone conductors is 25 feet and earth resistivity is 100 meter-ohms. Since $25 \times \sqrt{900} = 750$ the chart is entered at the 750 point along the bottom scale. Moving vertically to the point of intersection with the $\rho = 100$ curve then horizontally to the left hand scale, the mutual impedance of .0013 ohms per kilofoot/Hertz is found. Multiplying this value of .0013 ohms per kilofoot/Hertz by 900 Hertz results in the 900 Hertz mutual impedance of 1.17 ohms per kilofoot. Thus where there is one ampere earth return current at 900 Hertz there would be an induced 900 Hz voltage to ground of 1.17 volts per kilofoot on unshielded telephone conductors.

3.6.2 Where the average earth resistivity of an area is not close enough to resistivity values on the curves in Figure 4 enter the chart at the point (d) $\sqrt{f}\,)/\sqrt{\rho}$ on the bottom scale (d = conductor separation in feet, f = frequency in Hertz and ρ = earth resistivity in meter-ohms). Follow the vertical line to the intersection with the $\rho = 1$ line and read Zm per Hertz of this point on the left scale of the Chart. For example had the earth resistivity for the illustration in Paragraph 3.6.1 been 500 meter-ohms the mutual impedance would have been 1.46 rather than 1.17 ohms per kilofoot.

3.7 Figure 5 has been prepared to provide a convenient means of determining $\sqrt{f}$ or $\sqrt{\rho}$ when needed. Enter the chart along the bottom horizontal scale at the value of f for ρ. Follow the vertical line to the point it intersects the curve. Read $\sqrt{f}$ or $\sqrt{\rho}$ at this point on the left scale of the chart.

4. SHIELD FACTORS (n)

4.1 An explanation of shielding is given in Paragraph 5 of TE & CM Section 451. Section 451 shows that the addition of a conductor between the power and telephone conductors through which current can flow between the power and telephone conductors will result in some reduction of the longitudinal induced voltage in the telephone conductor. Paragraph 5 of 451 also shows via shield factor discussion that there is minimal shielding at the 60 Hertz fundamental frequency and that shielding increases with frequency. Effects of shield resistance and resistance to earth of electrodes connecting shields to earth are also discussed.

4.1.1 Shield factor may be defined as the ratio of the voltage to ground in the telephone circuit (disturbed circuit) after introduction of the shielding circuit, to the nonshielded induced voltage to ground in the telephone circuit (disturbed circuit) with the current in the power circuit (disturbing circuit) remaining the same.

4.1.2 Shield factors are another valuable tool during noise investigation. Expected power influence, at any harmonic frequency, in an exposed telephone circuit can be calculated and compared to recorded measured values.

4.1.3 The magnitude of expected voltage to ground in a shielded telephone conductor may be found by multiplying the expected voltage to ground in a nonshielded conductor as found in Paragraph 3.1.3 by the shield factor.

4.2 The equation for calculating the shield factor when the shield conductor is close to the disturbed conductor and remote from the disturbing conductor is:

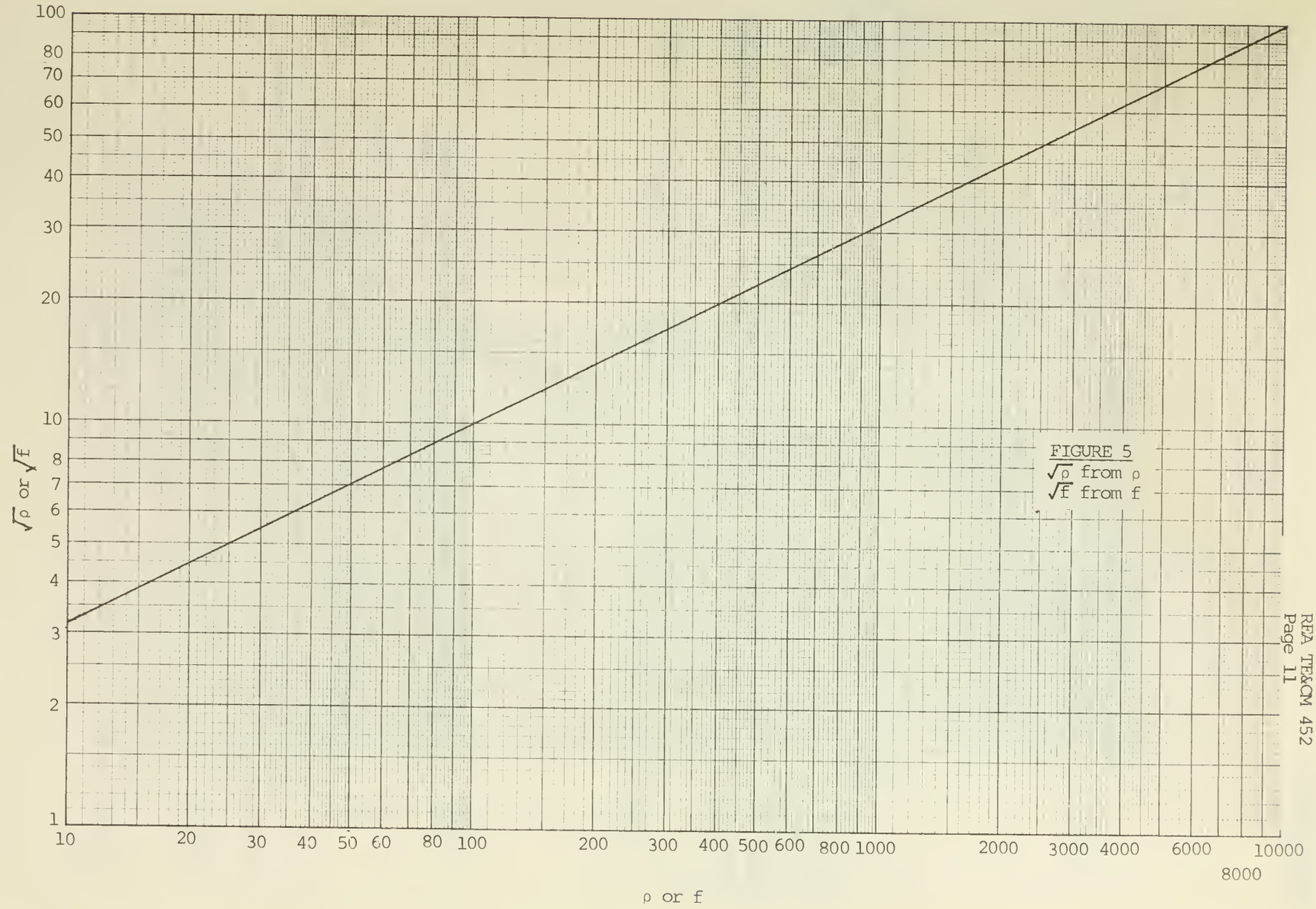


FIGURE 5
$\sqrt{\rho}$ from ρ
$\sqrt{f}$ from f

$$\eta = \frac{Z_{22} - Z_{23} + \frac{R_T}{\ell}}{Z_{22} + \frac{R_T}{\ell}} \approx \frac{Z_{22}}{Z_{22} + \frac{R_T}{\ell}}$$

Where: η = Shield factor
Z_{22} = Ground return self impedance of the shield in ohms per kilofoot.
Z_{23} = Ground return mutual impedance between the shield and telephone conductors in ohms per kilofoot.
R_T = Total resistance to earth of earth electrodes in ohms.
ℓ = Length of cable in kilofeet

4.2.1 Since most telephone noise investigations will involve cables with nonmagnetic shields, (Aluminum, copper, etc.), the equation in Paragraph 4.2 can be simplified. For a nonmagnetic shield, the internal self reactance is negligible and the internal self resistance is the effective resistance of the cable shield. The ground return self impedance (Z_{22}) of the cable shield is thus equal to the external self impedance (Z^O_{22}) plus the effective resistance (r_{22}). The self impedance (Z_{22}) of the cable shield differs from the mutual impedance (Z_{23}) between the shield and the telephone conductors only by the effective resistance (r_{22}) of the cable shield ($Z_{22} - Z_{23} = r_{22}$).

4.2.2 Applying this to the equation in Paragraph 4.2 produces the following equation for application to cables with nonmagnetic shields:

$$\eta = \frac{r_{22} + \frac{R_T}{\ell}}{r_{22} + \frac{R_T}{\ell} + Z^O_{22}}$$

Where: η = Shield factor
r_{22} = Effective resistance of shield in ohms per kilofoot
Z^O_{22} = External self impedance of the shield circuit in ohms per kilofoot.
R_T = Total resistance to earth of earth electrodes in ohms.
ℓ = Length of cable in kilofeet

4.3 Carsons equation, discussed in Paragraph 3, can be simplified to the following form for calculation of the self and mutual impedance of earth return circuits:

$$Z_{22} = \frac{r}{n} + 0.3 \times 10^{-3} f + j\, 0.882 \times 10^{-3} f \times \log_{10}\left(\frac{2280}{d\sqrt{\frac{f}{\rho}}}\right)$$

$$Z_{23} = 0.3 \times 10^{-3} f + j\, 0.882 \times 10^{-3} f \times \log_{10}\left(\frac{2280}{d\sqrt{\frac{f}{\rho}}}\right)$$

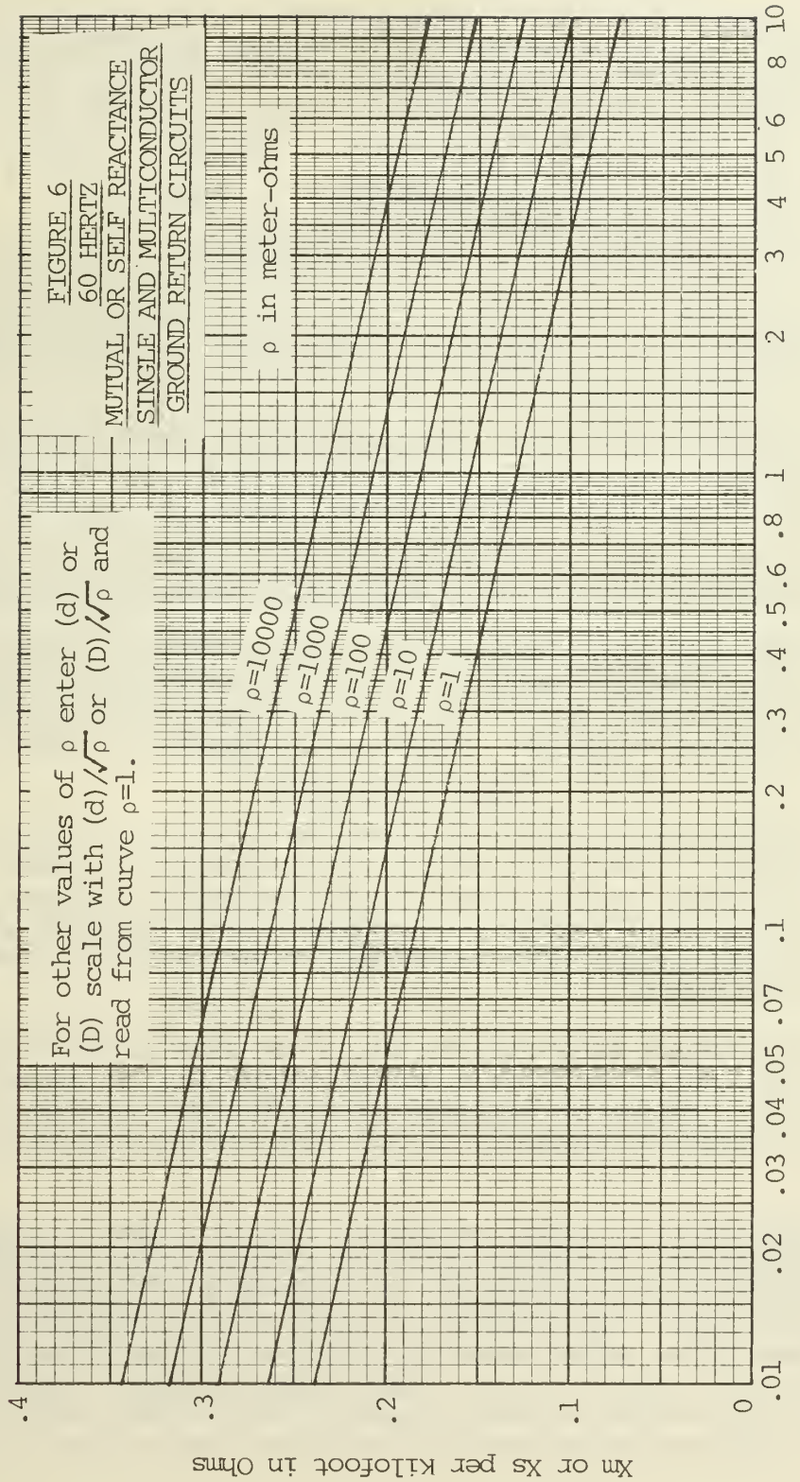


FIGURE 6
60 HERTZ
MUTUAL OR SELF REACTANCE
SINGLE AND MULTICONDUCTOR
GROUND RETURN CIRCUITS
For other values of ρ enter (d) or (D) scale with (d)/√ρ or (D)/√ρ and read from curve ρ=1.
ρ in meter-ohms
ρ=10000
ρ=1000
ρ=100
ρ=10
ρ=1
Xm or Xs per kilofoot in Ohms
.4
.3
.2
.1
0
.01 .02 .03 .04 .05 .07 .1 .2 .3 .4 .5 .6 .8 1 2 3 4 5 6 8 10
Conductor Separation or Radius (d) or (D) in Feet

Where: Z_{22} = Ground return self impedance of the shield in ohms per kilofoot.
Z_{23} = Ground return mutual impedance between the shield and telephone conductors in ohms per kilofoot.
$\frac{r}{n}$ = Effective resistance of shield circuit in ohms per kilofoot (where shield circuit is a single metallic shield conductor, n = 1).
f = Frequency in Hertz.
D = Radius of shield conductor in feet.
ρ = Earth resistivity in meter-ohms.
d = Radial distance between conductors.

4.3.1 As was shown in Paragraph 4.2.1 $Z_{22} = r_{22} + Z^{o}_{22}$. Z^{o}_{22} is a complex impedance and in rectangular form is equal to an external resistance term and an external reactance term, $Z^{o}_{22} = R_s + j\, x_s$.

4.3.2 The earth return mutual impedance (Z_{23}) between circuits is a complex impedance. In rectangular form it is equal to a mutual resistance term plus a mutual reactance term, $Z_{23} = R_m + X_m$.

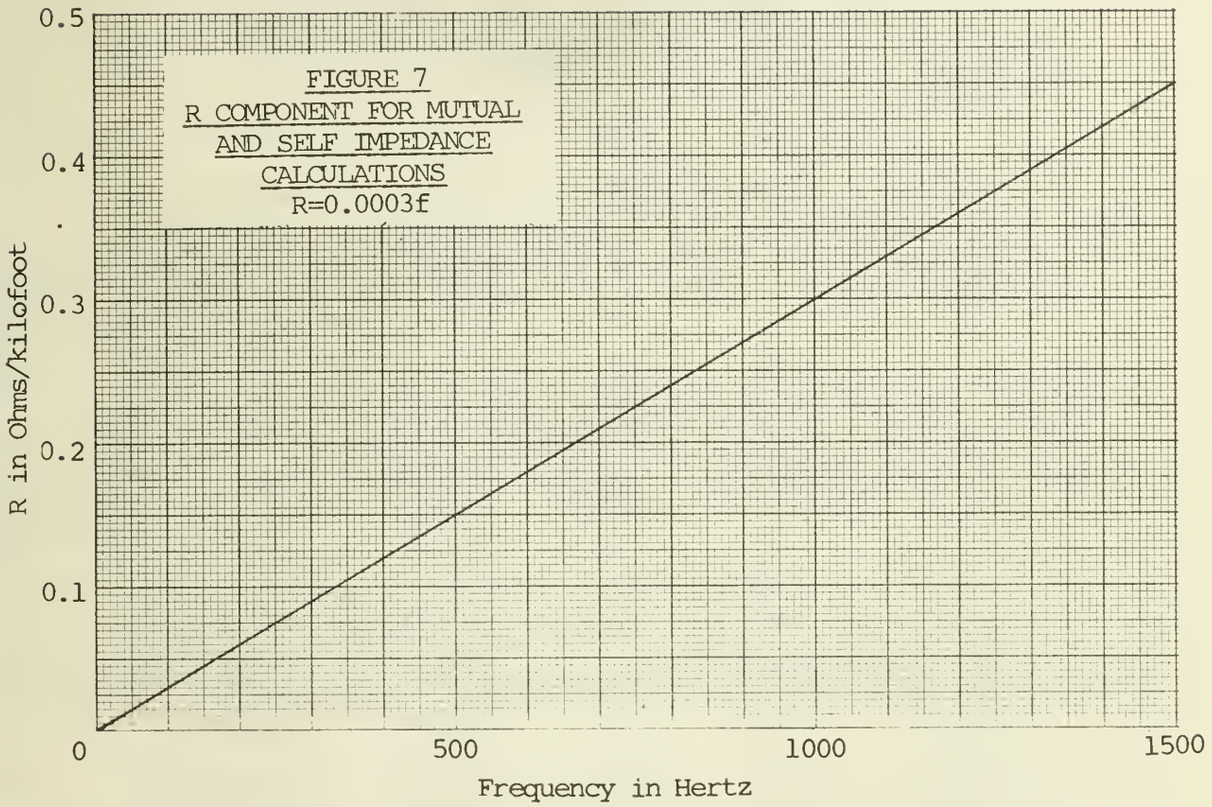
4.3.3 These equations are approximations that are valid for the separations and frequencies most often encountered during noise investigations.

4.4 Curves in Figure 6 are for calculating 60 Hertz self or mutual reactances and are useful for finding 60 Hertz shield factors. Since these curves are intended for this single application, the (d) or (D) scale has only been plotted to 10 feet. Where mutual impedance between the power and telephone systems is desired refer to Paragraph 3.

4.4.1 Enter the bottom horizontal scale of Figure 6 at the value corresponding to the radius of the shield conductor in feet. (To find the radius of a cable shield in feet, divide the shield diameter in inches by 24). From this point, follow the vertical line to the point where it intersects the appropriate earth resistivity curve. Read the reactance on the left vertical scale.

4.4.2 Where average earth resistivity is not close to one shown in the curves, enter the scale along the bottom line at the point $(d)/\sqrt{\rho}$ or $(D)/\sqrt{\rho}$. Follow the vertical line to the intersection with the $\rho = 1$ curve and read the reactance of this point on the left vertical scale of Figure 6.

4.4.3 The external or mutual resistance term is needed to complete the external self or mutual impedance in rectangular form. This term is a direct function of frequency and is independent of separation or radius and earth resistivity. The external or mutual resistance term shown in Paragraph 4.3 is $0.3 \times 10^{-3} f$. Figure 7 provides the resistance term value for frequencies of interest for most noise investigations. Enter the Figure 7 horizontal scale at the desired frequency. Follow the vertical line to the point where it intersects and read the resistance term on the left vertical scale.



4.4.4 Assume the 60 Hertz shield factor is desired for 10 kilofeet of 25-24 filled cable with an 8 mil aluminum shield, in an area with 100 meter ohms earth resistivity. The cable diameter is found to be 0.61 inch from Table I of this TE&CM and the shield resistance is 1.1 ohms per kilofoot from Table 1 in TE&CM Section 451.

TABLE I

CABLE DIAMETERS IN INCHES FILLED CABLES

PAIRS	GAUGES			
	26	24	22	19
6	-	.41	.44	.51
12	-	.49	.54	.77
18	-	.53	.63	.82
25	.50	.61	.70	.92
50	.62	.76	.90	1.29
75	.70	.88	1.09	1.57
100	.77	.99	1.22	1.73
150	.93	1.19	1.48	2.09
200	1.08	1.44	1.66	2.37
300	1.26	1.62	2.01	2.79
400	1.43	1.86	2.30	-
600	1.74	2.29	2.81	-

NOTE: These diameters apply to the following shield materials; 5 mil copper, 10 mil copper, 8 mil aluminum, and 6 mil copper steel.

4.4.4.1 From Figure 7, we find the external resistance term for 60 Hertz is 0.018 ohms/kft. Dividing the cable diameter in inches (0.61) by 24 we obtain a cable radius of 0.025 feet. Figure 6 shows the external self reactance for a cable with 0.025 foot radius in an area of 100 meter-ohms earth resistivity is 0.265 ohms/kft.

4.4.4.2 Placing these values in the equation shown in Paragraph 4.2 produces:

$$\eta = \frac{r_{22} + \frac{R_T}{\ell}}{r_{22} + \frac{R_T}{\ell} + Z^o_{22}} = \frac{1.1 + \frac{10}{10}}{1.1 + \frac{10}{10} + 0.018 + j\,0.265} = \frac{2.1}{2.118 + j\,0.265}$$

4.4.4.3 The denominator (2.118 + j 0.265) is the ground return self impedance (Z_{22}) of the shield circuit in rectangular form with the added term for the resistance to earth of the end electrodes. Before the division operation can be completed the denominator must be converted from rectangular to polar form. The magnitude of the impedance (Z) = $\sqrt{R^2 + X^2}$. This gives $\frac{2.1}{2.13} = 0.99 = n$. The phase angle involved may be ignored for shield factor applications discussed here.

4.5 Curves in Figure 8 are for calculating 540 Hertz external or mutual reactances and are useful for finding 540 Hertz shield factors. Since they are intended for this single purpose the (d) or (D) scale has only been plotted to 10 feet. Refer to Paragraph 3 for mutual impedance between the power and telephone systems.

4.5.1 Enter Figure 8's bottom horizontal scale at the value corresponding to the radius of the shield conductor in feet. (To find the radius of a shield conductor in feet divide the shield diameter in inches by 24.) From this point follow the vertical line to the point where it intersects the appropriate earth resistivity curve. Read the reactance of this point on the left vertical scale.

4.5.2 Where the average earth resistivity is not close to one shown in the curves enter the scale along the bottom line at the value corresponding to $(d)/\sqrt{\rho}$ or $(D)/\sqrt{\rho}$. Follow the vertical line to the intersection with the $\rho = 1$ curve and read the reactance of this point on the left vertical scale of Figure 8.

4.5.3 The external or mutual resistance term is needed to complete the rectangular form of the external self or mutual impedance. The method for obtaining this term is discussed in detail in Paragraph 4.4.3.

4.5.4 Assume the shield factor is desired at 540 Hertz for the same cable described in Paragraph 4.4.4.

4.5.4.1 From Figure 7, the external resistance term for 540 Hertz is 0.162/kft. The external self reactance (from Figure 8) for a cable with 0.025 foot radius in an area of 100 meter-ohms earth resistivity is 2.19 ohms/kft.

4.5.4.2 Placing these values in the equation shown in Paragraph 4.2 produces:

$$\eta = \frac{r_{22} + \frac{R_T}{\ell}}{r_{22} + \frac{R_T}{\ell} + Z^0_{22}} = \frac{1.1 + \frac{10}{10}}{1.1 + \frac{10}{10} + 0.162 + j\ 2.19} = \frac{2.1}{2.262 + j\ 2.19} =$$

$$\frac{2.1}{3.15} = 0.67$$

Again phase angles are not necessary and are disregarded.

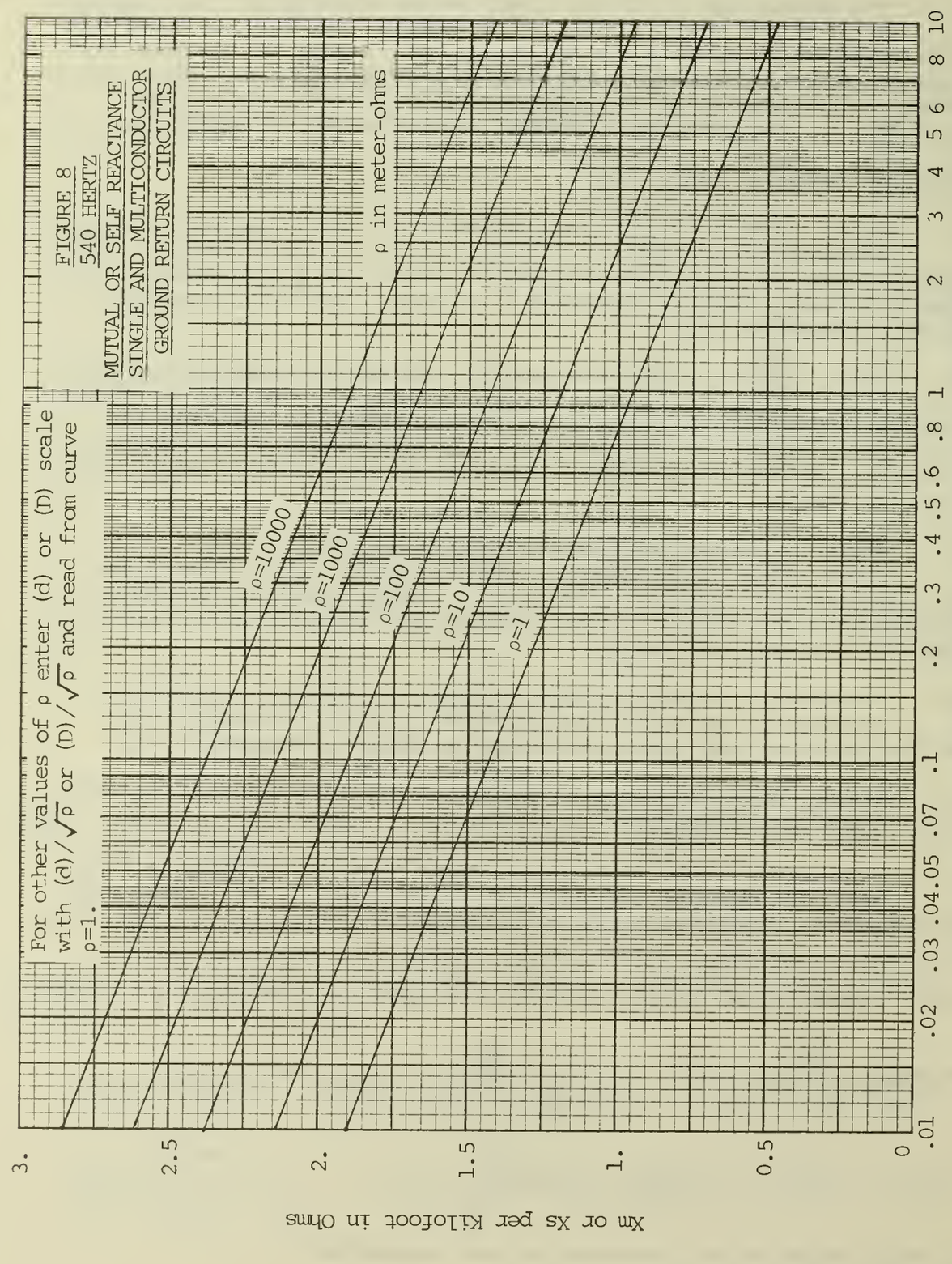


FIGURE 8
540 HERTZ
MUTUAL OR SELF REACTANCE
SINGLE AND MULTICONDUCTOR
GROUND RETURN CIRCUITS
ρ in meter-ohms
ρ=10000
ρ=1000
ρ=100
ρ=10
ρ=1
For other values of ρ enter (d) or (D) scale with (d)/√ρ or (D)/√ρ and read from curve ρ=1.
Xm or Xs per kilofoot in Ohms
3.
2.5
2.
1.5
1.
0.5
0
.01
.02
.03
.04
.05
.07
.1
.2
.3
.4
.5
.6
.8
1
2
3
4
5
6
8
10
Conductor Separation or Radius (d) or (D) in Feet

4.6 The application of Figure 6 and 8 should cover most situations where calculation of the shield factor is desired. There will be cases where a harmonic other than the ninth (540 Hertz) is predominant and the shield factor at this frequency is desired. Figure 9 has been developed for these cases. It provides the external self or mutual reactance in ohms/kft per Hertz. Enter the bottom horizontal scale at the value corresponding to (d) x $\sqrt{f}$ or (D) x $\sqrt{f}$. Follow the vertical line to the point it intersects the earth resistivity of interest and read the reactance for one Hertz on the left vertical scale. Multiply this value by f to obtain the desired reactance term. The external self or mutual resistance term is obtained from Figure 7 as described in Paragraph 4.43.

4.6.1 Assume the shield factor is desired at 900 Hertz for the cable described in Paragraph 4.4. From Figure 7, the external resistance term is 0.269 ohms/kft.

4.6.1.1 To find the external self reactance, determine $\sqrt{900}$. From Figure 5, we find $\sqrt{900}$ is 30. Multiplying 30 by the cable radius in feet (0.025) produces 0.75. Entering the bottom scale of Figure 9 at this value, we find the reactance per Hertz in an area with 100 meter-ohms earth resistivity is 0.00395. Multiplying this by 900 provides the total self reactance, 3.56 ohms/kft.

4.6.1.2 Placing these values in the equation shown in Paragraph 4.2 produces:

$$\eta = \frac{r_{22} + \frac{R_T}{\ell}}{r_{22} + \frac{R_T}{\ell} + Z^o_{22}} = \frac{1.1 + \frac{10}{10}}{1.1 + \frac{10}{10} + 0.269 + j\ 3.56} = \frac{2.1}{2.369 + j\ 3.56} =$$

$$\frac{2.1}{4.28} = 0.49$$

5. EXPECTED VOLTAGE TO GROUND

5.1 During noise investigations it may be desirable to determine if the measured power influence in a telephone circuit is that which should be expected for the measured earth return current of the power system, either at the fundamental frequency or at a harmonic frequency. The expected voltage to ground can be calculated from the three factors discussed in Paragraph 2, 3, and 4. The resulting voltage can then be converted to power influence.

5.1.1 Calculation of expected voltage to ground is not precise. There are unpredictable variables, broad assumptions and averaging involved, all of which influence the accuracy of the results. For example, separation between power and telephone conductors is assumed constant but actually varies throughout the length of exposure. The actual value used in the calculations is an estimate of average separation.

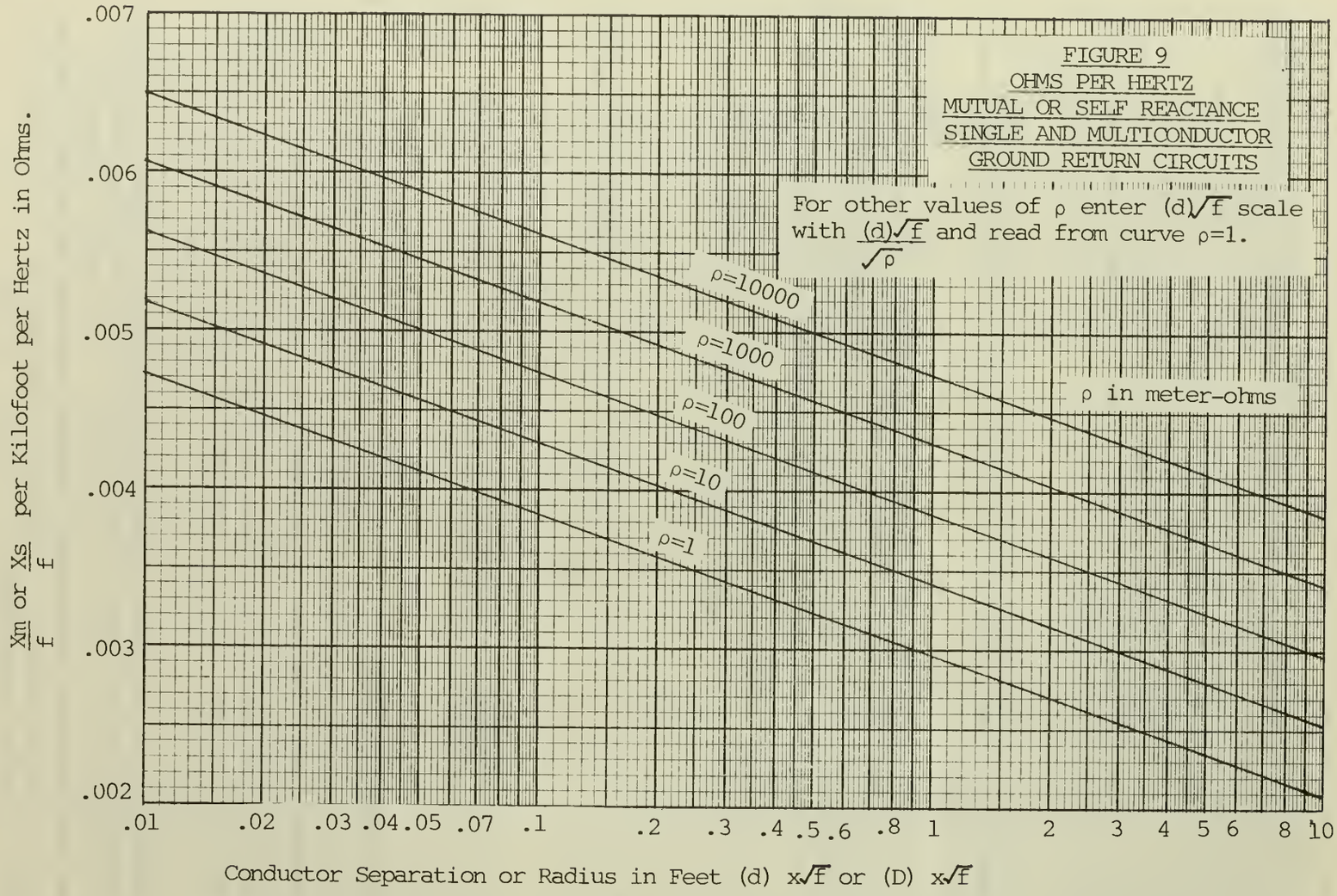


FIGURE 9
OHMS PER HERTZ
MUTUAL OR SELF REACTANCE
SINGLE AND MULTICONDUCTOR
GROUND RETURN CIRCUITS
For other values of ρ enter (d)√f scale with (d)√f / √ρ and read from curve ρ=1.
ρ=10000
ρ=1000
ρ=100
ρ=10
ρ=1
ρ in meter-ohms
Xm/f or Xs/f per Kilofoot per Hertz in Ohms.
.007
.006
.005
.004
.003
.002
.01
.02
.03
.04
.05
.07
.1
.2
.3
.4
.5
.6
.8
1
2
3
4
5
6
8
10
Conductor Separation or Radius in Feet (d) x√f or (D) x√f

5.1.2 Earth resistivity along a cable route will usually vary over a wide range. An average value based on several measured values along a route will provide an acceptable calculated power influence. It can be shown that at 60 Hertz an unshielded telephone conductor 10,000 feet long located 30 feet from a parallel power conductor with one ampere earth return current will have power influence as shown with various values of earth resistivity.

Earth Resistivity in Meter-ohms	Power Influence in dBrn
100	92.8
1000	94.6
10000	96.2

These values are within the allowable tolerance for expected voltage to ground calculations. They also indicate that calculations for areas where measured earth resistivity is unavailable may be completed using an assumed value of 1000 meter-ohms.

5.1.3 Power system earth return current will vary through the length of exposure. The value used in calculations is usually an average of two or three measurements of the earth return current along the length of exposure.

5.1.4 Calculations are usually accurate enough to determine whether measured power influence is reasonable and what is expected for the existing earth return current. When 4 dBrn or less differences are found, measured influence values are considered valid.

5.2 The total length of exposure should be surveyed, recording the lengths where separation between the power and telephone system is essentially the same. Where staking sheets are not available, lengths of exposure may be measured with an automobile odometer. Separations which vary by up to ten feet are considered to be essentially the same and the average separation for the exposure length estimated. Where greater variations are found, they should be treated as new exposure lengths.

5.2.1 The earth return current of the power system should be measured during worst case, highest expected magnitude, times at least once along each exposure length. Where a long exposure length occurs (in excess of five kilofeet), two or more measurements should be made and results averaged. This will be discussed in detail in TE&CM 452.2 and 452.3.

5.2.2 After determining: exposure lengths, separations between power and communications circuits, power system earth return current, average earth resistivity and mutual impedance between power and communications circuits as per Paragraph 3, and shield factor as per Paragraph 4, the expected open circuit voltage to ground can be calculated by the equation below.

$$E_G = Z_{12} I_{GR} \ell \eta$$

Where: E_G = Voltage to ground in volts
Z_{12} = Mutual impedance between the power and telephone circuits in ohms per kilofoot
I_{GR} = Earth return current of the power system in amperes
ℓ = Length of exposure in kilofeet
η = Shield factor for the telephone cable

5.3 Since most test equipment for measuring voltage to ground provide results in dBrn noise-to-ground (N_g) rather than volts, it is desirable to convert the expected voltage to ground (E_G) to dBrn. TE&CM Section 451 shows that the voltage reference for 0dBrn noise-to-ground is 2.45 millivolts to ground. The expected voltage to ground can be converted to noise-to-ground in dBrn with the following equation:

$$Ng \text{ dBrn} = 20 \log \frac{E_G}{2.45 \times 10^{-3}}$$

5.3.1 The noise-to-ground in dBrn provided by the equation in Paragraph 5.3 is the value which will be read on noise measuring sets capable of single frequency measurement, set for 3kHz Flat weighting. It is necessary to add 40 dBrn to obtain power influence.

5.3.2 The equation can be adjusted to provide power influence in dBrn. When the adjusted equation is used, it is necessary to add 40 dB to noise measuring set readings of noise-to-ground before comparison to the expected power influence. The adjusted equation is:

$$PI \text{ dBrn} = 20 \log \frac{E_G}{24.5 \times 10^{-6}}$$

5.3.3 The curve in Figure 10 has been prepared to provide a convenient means of converting voltage to ground to dBrn of power influence for 3 kHz Flat weighted measurements. Enter the chart along the left at the value corresponding to the voltage to ground. Follow the horizontal line to the point of intersection with the curve. Follow the vertical line from this point to the bottom scale and read the dBrn power influence.

5.3.4 When power influence at a specific frequency is desired in dBrnC, Table II (Page 30) may be used. Subtract the C-message weighting (found in Table II for the frequency of interest) from the 3kHz Flat values either calculated or found in Figure 10 for that frequency.

5.4 As an example of expected voltage to ground calculations, we can look at a 25 pair 24 gauge filled cable, with 8 mil aluminum shield, 10 kilofoot in length, with a 5 ohm ground at each end, in an area with 1000 meter ohms earth resistivity. The cable is exposed, along the entire length, to a 3-phase power line with an average separation of 40 feet. Since the ninth harmonic (540 Hertz) is a common problem harmonic, we will calculate the expected noise-to-ground at 540 Hertz. Assuming some resonance exists in the power system an average measured 540 Hz earth return current of 0.5 ampere will be used.

5.4.1 The mutual impedance between the power and telephone system is found from in Figure 3. For a 40 foot radial separation and earth resistivity of 1000 meter-ohms, Z_{23} is 0.91 ohms per kilofoot.

5.4.2 The shield factor is calculated next. Table I shows a 25 pair 24 gauge filled cable has a diameter of 0.61 inches. Table 1 in TE&CM Section 451 shows the shield resistance for this cable is 1.1 ohms per kilofoot. The external resistance term of the complex self impedance is found from Figure 7 to be 0.162 ohms per kilofoot. Cable radius in feet is found by dividing the diameter by 24, thus, 0.61/24 = 0.025 feet. Using this value in Figure 8, we find the self reactance term is 2.43 ohms.

5.4.3 Substituting these values in the equation in Paragraph 4.2 produces a shield factor of:

$$\eta = \frac{r_{22} + \frac{R_T}{\ell}}{r_{22} + \frac{R_T}{\ell} + Z^o_{22}} = \frac{1.1 + \frac{10}{10}}{1.1 + \frac{10}{10} + 0.162 + j\ 2.43} = \frac{2.1}{2.262 + j\ 2.43} =$$

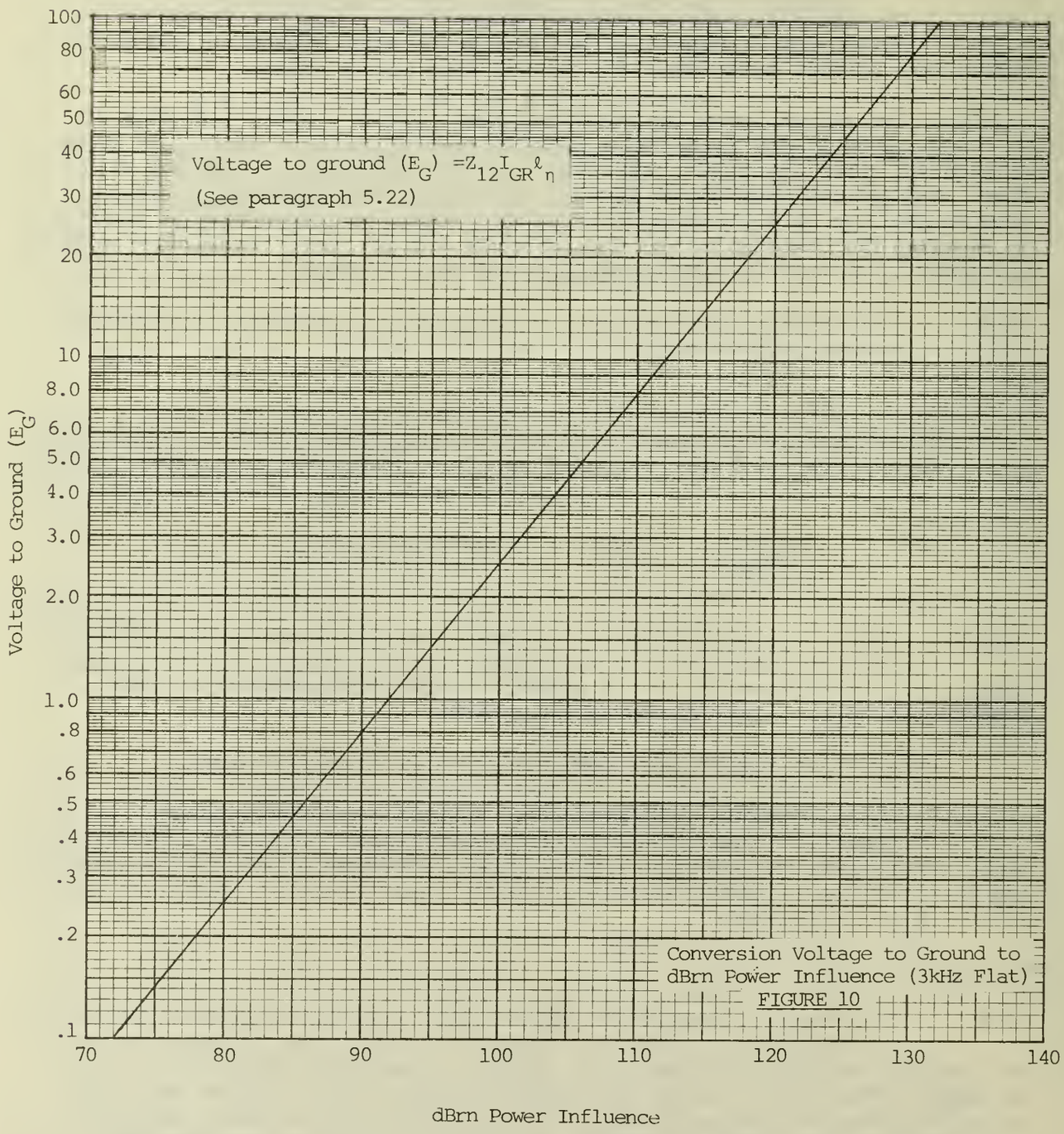
$$\frac{2.1}{3.32} = 0.63 = 540 \text{ Hz Shield Factor}$$

5.4.4 All the variables are now available for application in the equation shown in Paragraph 5.22 for calculation of expected 540 Hz voltage to ground; Z_{12} = 0.91 ohms, I_{GR} = 0.5 ampere, ℓ = 10 kilofeet, and η = 0.63. Substituting these values in the equation gives;

$$E_G = (0.91)\ (0.5)\ (10)\ (0.63) = 2.87 \text{ volts at 540 Hz.}$$

5.4.5 When desired E_G may be converted to dBrn 3kHz Flat by using Figure 10. For 2.87 volts the expected power influence is 101.2 dBrn. This can be converted to expected power influence in dBrnc by subtracting the C-message weighting factor for 540 Hz. (see Table II), resulting in 101.2 - 6.3 = 94.9 dBrnc.

5.5 The foregoing example was simple since only one cable size was involved and the separation between the power and telephone system was uniform throughout the length of exposure. Such conditions will rarely be found in the field. Cables will usually change size at one or more locations and power or telephone lines will change sides of the road. We will now consider a more typical example. Figure 11 illustrates a more typical condition which might be found in the field during a noise investigation.



Conversion Voltage to Ground to dBrn Power Influence (3kHz Flat)

FIGURE 10

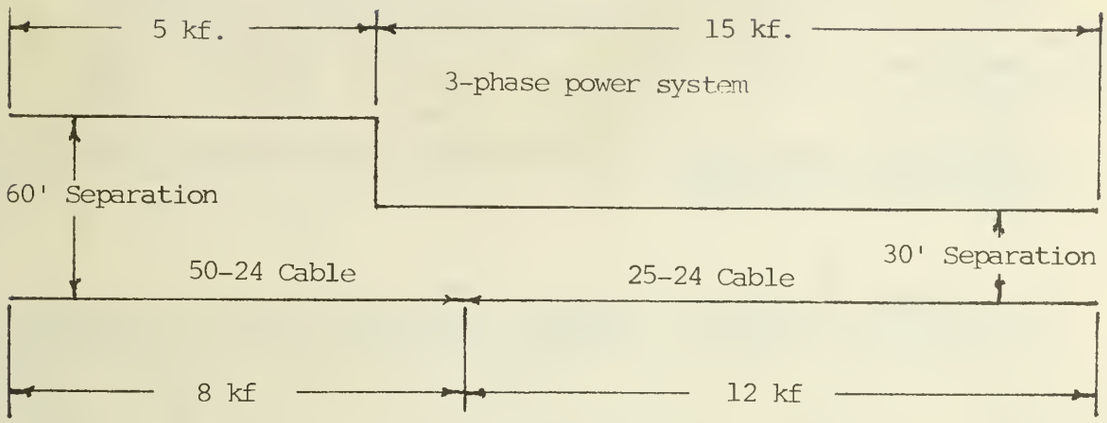


FIGURE 11: SAMPLE EXPOSURE

5.5.1 An 540 Hz earth return current of 0.5 ampere will be assumed in area of 1000 meter-ohms earth resistivity. There are two methods for calculating the expected voltage to ground along this exposure. First, the separations, cable diameters, and shield resistances can be averaged for the total length and a single calculation can be made. Second, the calculations can be made for each different exposure length, three in this example, and the results added. Calculations will be shown for both methods to illustrate that the results are the same. The resistance of the end grounds will be assumed to be zero to permit easier comparison.

5.5.2 Average the separation between the power and telephone systems to initiate the first method. (5x60) + (15x30) = 300 + 450 = 750/20 = 37.5 feet average separation. The average mutual impedance of 0.92 ohms per kilofoot is found in Figure 3 for 37.5 feet and 1000 meter-ohms earth resistivity.

5.5.3 The shield factor is calculated next. Table I shows that the diameter of a 50 pair 24 gauge filled cable with 8 mil aluminum shield is 0.76 inches and 25 pair 24 gauge filled cable diameter is 0.61 inches. These are averaged, (8x0.76) + (12x0.61) = 6.08 + 7.32 = 13.4/20 = 0.67 inches average shield diameter.

5.5.3.1 From Figure 7 the 540 Hertz external resistance term is 0.162 ohms per kilofoot. Average shield radius in feet is found by dividing the average diameter in inches by 24, thus, 0.67/24 = 0.028 feet. Using this value the self reactance of 2.4 ohms is found in Figure 8.

5.5.3.2 Table 1 in TE&CM 451 shows the shield resistance of a 50 pair 24 gauge filled cable with 8 mil aluminum shield is 0.88 ohms per kilofoot and a 25 pair 24 gauge filled cable is 1.1 ohms per kilofoot. Averaging these gives (8x0.88) + (12x1.1) = 7.04 + 13.2 = 20.24/20 = 1.01 ohms per kilofoot.

5.5.3.3 Substituting these values in the equation shown for shield factor in Paragraph 4.2 gives:

$$\eta = \frac{r22 + \frac{R_T}{\ell}}{r22 + \frac{R_T}{\ell} + Zo_{22}} = \frac{1.01 + \frac{0}{20}}{1.01 + \frac{0}{20} + 0.162 + j\ 2.4} = \frac{1.01}{1.172 + j\ 2.4} =$$

$$\frac{1.01}{2.67} = 0.38 = 540 \text{ Hz Shield Factor}$$

5.5.4 All the data is now available for the equation in Paragraph 5.22 for calculation of expected voltage to ground. Z_{12} = 0.92 ohms per kilofoot IGR = 0.5 ampere, ℓ = 20 kilofeet, and η = 0.38. Substituting these values in the equation gives:

E_G = (0.92) (0.5) (20) (0.38) = 3.5 volts to ground at 540 Hz.

5.5.5 From Figure 10, the 3 kHz Flat power influence is found to be 103.1 dBrn.

5.6 The expected voltage to ground can also be calculated by the second method, calculating E_G for each different exposure length and adding the results to obtain the total expected voltage. There are three different exposures in Figure 11. The 50 pair 24 gauge cable parallels the power line for a distance of 5 kilofeet with a 60 foot separation, the 50 pair 24 gauge cable parallels the power line for a distance of 3 kilofeet with a 30 foot separation, and the 25 pair 24 gauge cable parallels the power line for a distance of 12 kilofeet with a 30 foot separation.

5.6.1 Figure 3 shows the mutual impedance for the 5 kilofoot exposure length is 0.79 ohms per kilofoot. The external resistance term at 540 Hertz for a 50-24 filled cable (from Figure 7) is 0.162 ohms per kilofoot. The cable radius in feet is 0.76/24 = 0.032 feet. The external self reactance is 2.14 ohms as found in Figure 8.

5.6.1.1 Substituting values in the equation for shield factor gives:

$$\eta = \frac{0.88}{0.88 + 0.162 + j\ 2.14} = \frac{0.88}{1.042 + j\ 2.14} = \frac{0.88}{2.38} = 0.37 = 540 \text{ Hz. Shield Factor}$$

5.6.1.2 The expected voltage to ground for this exposure length is (0.79) (0.5) (5) (0.37) = 0.73 volts to ground.

5.6.2 There is only one difference between the 3 kilofoot exposure length and the 5 kilofoot discussed in Paragraph 5.61. The separation between the power line and the telephone cable is 30 feet rather than 60 feet. From Figure 3, the mutual impedance for a 30 foot separation is 0.92 ohms per kilofoot. The expected voltage to ground for this exposure is (0.92) (0.5) (3) (0.37) = 0.51 volts to ground.

5.6.3 The mutual impedance between the power line and the telephone cable for the remaining 12 kilofoot exposure length with 30 foot separation will be same as for the 3 kilofoot exposure discussed in Paragraph 5.62, 0.92 ohms per kilofoot. The external resistance term of the cable at 540 Hertz is 0.162 ohms (from Figure 7). The cable radius in feet for a 25 pair 24 gauge filled cable with an 8 mil aluminum shield is 0.61/24 = 0.025 feet. From Figure 8, the external self impedance of a cable with 0.025 foot radius is 2.42 ohms.

5.6.3.1 Substituting values in the equation for shield factor gives:

$$\eta = \frac{1.1}{1.1 + 0.162 + j\,2.42} = \frac{1.1}{1.262 + j\,2.42} = \frac{1.1}{2.73} = 0.40 = \text{540 Hz Shield Factor}$$

5.6.3.2 The expected voltage to ground for this exposure is (0.92) (0.5) (12) (0.4) = 2.2 volts to ground.

5.6.4 Adding the expected voltages to ground for the three exposure lengths gives 0.73 + 0.51 + 2.2 = 3.44 volts to ground. This is 0.6 volts less than the value obtained by averaging in Paragraph 5.54.

5.6.5 From Figure 10, the power influence for 3.44 volts to ground is 103 dBrn. This is 0.1 dBrn less than the 103.1 dBrn found by averaging.

5.7 The averaging method is recommended for calculation of expected voltages to ground. Calculation of the various exposure lengths individually works well if the ground resistances at each end are zero ohms. This condition does not occur in the field. Where there is resistance to ground at each end the problem of distributing its effects properly to the individual exposure lengths is quite complex.

5.8 There is another condition of the telephone system which has not been discussed. This is where cable shields have connections to ground electrodes at several locations along the cable route, for example, every two kilofeet. The expected voltage to ground may be calculated for such situations but the calculations are complex and will not be presented here.

5.8.1 Calculations of expected voltages to ground have been made for several exposures with distributed ground connections using the complex equations. These same calculations were then repeated assuming only a ground at each end of the cable. At 540 Hertz there was only about one dBrn difference in the power influence. This is not considered a significant difference.

5.8.2 Since the expected voltage to ground is calculated to determine if the measured voltage to ground in the telephone system is reasonable, calculations with a resistance to ground assumed at each end are accurate enough for practical comparisons.

5.8.3 The effects of distributed grounds are very important to system protection. This will be discussed in sections dealing with system protection considerations.

6. HARMONIC ANALYSIS OF POWER INFLUENCE ON TELEPHONE CABLE PAIR

6.1 One of the best means available for determining power system operating characteristics in an area is a well balanced telephone system. A telephone cable pair is equivalent to a long probe wire and measurement of the induced longitudinal voltage to ground at the power line fundamental and harmonic frequencies can provide valuable information relative to the power system operation. While the earth return currents due to unbalanced conditions in the power system cannot be calculated, specific operational problem areas can often be clearly identified.

6.2 Study of recorded results from a harmonic analysis of power influence on a telephone cable pair may provide information that will identify and locate power system problems. Even when this is not accomplished there is usually a clear indication as to where additional measurements can be made to better identify a problem.

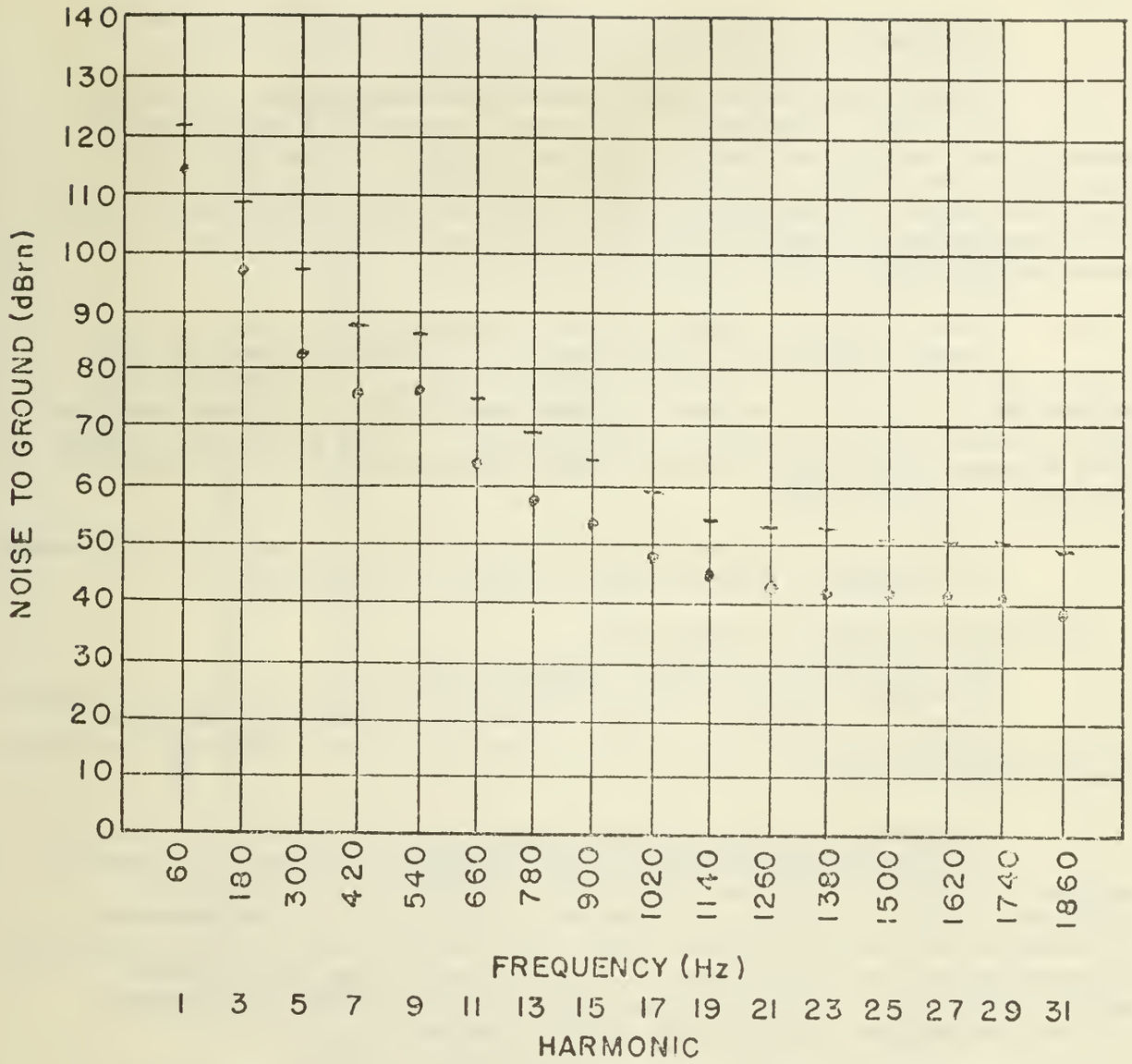
6.2.1 This procedure entails measuring power influence at fundamental and harmonic frequencies at a subscriber location. When an idle cable pair is available, it should be used for the measurement in lieu of the working one.

6.2.2 Recorded results from these measurements are then compared to the average results of a noisy loop survey /2 (Figure 12). The mean (μ) and mean plus one sigma ($\mu + \sigma$) values have been plotted for each frequency of interest. Extensive surveying has shown that these plotted values are representative of those to be expected on noisy loops in most telephone companies.

6.3 Among the power line problem areas that can be identified are:

A - Poor balance in a 3-phase power system.
B - Excessive exposure length to single-phase power system.
C - Capacitors not working at a 3-phase capacitor bank installation. (open capacitor)
D - Malfunctioning capacitor banks. (Change in capacitance value)
E - Circuit resonance.
F - Power transformer problems.
G - Harmonics from generator or motor.
H - Harmonics from SCR control devices.
I - Harmonics from Rectrifier (ac and dc side).

/2 Bell Telephone Laboratories, Inc., 1971 Noise Loop Survey



. Mean of survey (μ)
– $\mu + \sigma$ of survey

FIGURE 12
RESULTS OF NOISY LOOP SURVEY

6.3.1 Open shield circuits in the telephone company plant can also be detected.

6.3.2 Each of the problem areas listed has its own pattern of harmonics that will exceed the ($\mu + \sigma$) point. Where only a single problem exists it will usually be clearly indicated. Analysis becomes more difficult where two or more problems exist along a single route. Close study will usually determine the predominant problem area and after it has been corrected a new measurement will provide data which will permit identification of the second problem area.

6.3.3 Where results of power influence measurements are equal to or less than the plotted ($\mu + \sigma$) values and the telephone plant has good balance (60 dB or better), there is no noise problem. If C-message factors are applied to the ($\mu + \sigma$) values and these results added on a power summation basis, resulting power influence is about 86 dBrnc. With a cable pair having 60 dB balance, resulting circuit noise will be 26 dBrnc which is acceptable on long rural subscriber loops.

6.4 A detailed discussion of how to perform harmonic frequency measurements and interpret recorded results is given in TE&CM 452.1.

7. EXPLORING COIL STUDY OF POWER LINE

7.1 An exploring coil can be a valuable tool to quickly locate some types of power line problems. A coil is used with a spectrum analyzer to monitor earth return current of a power line at any harmonic frequency, anywhere along its entire length.

7.2 This method can be utilized either as the initial step of a specialized noise investigation or as an operation subsequent to harmonic analysis of power influence on a cable pair as discussed in Paragraph 2. Experience indicates that the ninth harmonic (540 Hertz) will be predominant in the majority of noise problems. Thus when using the exploring coil technique the spectrum analyzer should usually be set to monitor 540 Hertz. Where harmonic analysis of a cable pair has identified the predominant frequency the spectrum analyzer should be set at that frequency.

7.3 Study of a power line with the exploring coil is accomplished by pointing the hand held coil toward the power line from a vehicle while traveling along the line. By monitoring the harmonic level it can be determined where capacitor banks may be providing a low impedance path to ground for harmonic currents, the location of overexcited transformers, etc. Once this information is available more precise measurements can be completed to confirm the problem location and severity.

7.4 A detailed discussion of how to perform an exploring coil study of a power line and interpretation of the findings is given in TE&CM 452.2.

8. TELEPHONE INFLUENCE FACTOR (TIF)

TABLE II

POWER HARMONIC C-MESSAGE WEIGHTING FACTORS

FREQUENCY	60-HERTZ HARMONIC	C-MESSAGE FACTOR -dB	RATIO $C\text{-}M_s$ G Cf	FREQUENCY	60-HERTZ HARMONIC	C-MESSAGE FACTOR -dB	RATIO $C\text{-}M_s$ G Cf
60	1	-55.7	0.0016	1380	23	-0.7	0.920
120	2	-37.8	0.013	1500	25	-1.0	0.890
180	3	-27.5	0.042	1620	27	-1.1	0.880
240	4	-21.2	0.087	1740	29	-1.2	0.870
300	5	-16.5	0.150	1800	30	-1.3	0.860
360	6	-13.1	0.222	1860	31	-1.3	0.860
420	7	-10.2	0.310	1980	33	-1.3	0.860
480	8	- 8.1	0.395	2100	35	-1.3	0.860
540	9	- 6.3	0.490	2220	37	-1.3	0.860
600	10	- 4.7	0.580	2340	39	-1.3	0.860
660	11	- 3.3	0.685	2460	41	-1.4	0.850
720	12	- 2.3	0.770	2580	43	-1.5	0.840
780	13	- 1.6	0.830	2700	45	-1.7	0.820
840	14	- 1.0	0.890	2820	47	-1.9	0.800
900	15	- 0.6	0.930	2940	49	-2.2	0.775
960	16	- 0.2	0.970	3000	50	-2.5	0.750
1020	17	- 0	1.000	3060	51	-3.0	0.700
1080	18	- 0.1	0.990	3180	53	-4.0	0.630
1140	19	- 0.1	0.990	3300	55	-5.2	0.550
1200	20	- 0.2	0.970	3480	57	-7.3	0.430
1260	21	- 0.4	0.950	3540	59	-8.2	0.390
				4500	75	-21.2	0.084

8.1 TE&CM Section 451 shows magnetic induction is an important source of power system interference on telephone lines, if currents in the various phases of power line are perfectly balanced, inductive effects should cancel out. Also when unbalance does exist, if the total unbalance current is carried in a neutral conductor located close to the other power conductors, and if the difference in spacing between the telephone line and the various power conductors can be ignored, inductive effects would again cancel out. The real concern, therefore, is with the part of the phase unbalance which does not flow in the power line neutral conductor, that is, we are concerned with the earth return current.

8.2 Often it is the TIF-weighted value of earth return current, or earth return I·T which is of greatest interest. Telephone Influence Factor or TIF is an index to the interfering effect of power system currents or voltages on nearby telephone circuits.

8.2.1 TIF weighting (W_f) is a frequency factor composed of:

a. C-Message weighting factor,
b. A frequency proportional factor (because coupling between power and telephone lines is roughly proportional to frequency), and
c. A constant factor (arbitrarily chosen to give a value of 5000 for W_f at f equals 1000 Hertz).

8.2.2 Thus:

$$W_f = 5fC_f$$

Where: C_f = The C-Message weighting factor at frequency f.

8.3 The TIF weighted amplitude of a complex waveform is the root-sum-square of the TIF weighted voltage or current amplitude of all the individual frequency components, including the fundamental. For the reasons discussed in Paragraph 1.4, only the current waveform equation will be considered here. The TIF weighted current amplitude is given by:

$$\text{TIF weighted current magnitude} = \sqrt{\Sigma\ (I_f \cdot W_f)^2}$$

8.4 TIF weighting factors for power line harmonic frequencies of interest are shown in Table III. C-Message weighting factors are shown in Table II. TIF values were derived from C-Message using the equation in Paragraph 8.2.2 and may differ from other tabulations.

9. MEASUREMENT OF EARTH RETURN CURRENT

9.1 Power system earth return currents can be determined by telephone engineers prior to contacting the power company, providing valuable information to the telephone engineer. Analysis of the power system harmonic earth return currents will often identify problems in power systems which lead

TABLE III

POWER HARMONIC TIF WEIGHTING FACTORS

FREQUENCY	60 HERTZ HARMONIC	TIF (Wf) dB	RATIO TIF Wf	FREQUENCY	60 HERTZ HARMONIC	TIF (Wf) dB	RATIO TIF Wf
60	1	-6.1	0.5	1500	25	76.5	6680
120	2	18.1	8	1620	27	77.1	7130
180	3	31.6	38	1740	29	77.6	7570
240	4	40.4	105	1800	30	77.8	7740
300	5	47.0	225	1860	31	78.1	8000
360	6	52.0	400	1980	33	78.6	8510
420	7	56.3	650	2100	35	79.1	9030
480	8	59.6	950	2220	37	79.6	9550
540	9	62.4	1320	2340	39	80.1	10060
600	10	64.8	1740	2460	41	80.4	10460
660	11	67.1	2260	2580	43	80.7	10840
720	12	68.8	2770	2700	45	80.9	11070
780	13	70.2	3240	2820	47	81.0	11280
840	14	71.5	3740	2940	49	81.1	11390
900	15	72.4	4190	3000	50	81.0	11250
960	16	73.4	4660	3060	51	80.6	10710
1020	17	74.2	5100	3180	53	80.0	10020
1080	18	74.6	5350	3300	55	79.2	9080
1140	19	75.0	5640	3480	57	77.5	7480
1200	20	75.3	5820	3540	59	76.8	6900
1260	21	75.5	5990	4500	75	65.5	1890
1380	23	76.1	6350				

to economic penalties to a power company. Also those problem areas which result in excessive noise to parallel telephone facilities can often be found. This information will generally facilitate more successful inductive coordination action with power people.

9.1.1 There are two methods whereby telephone employees can measure power line earth return currents without having to enlist power company assistance. Both methods will be discussed with the relative advantages and disadvantages of each.

9.1.2 One method involves use of an exploring coil (cited in Paragraph 7) and other method involves use of a 100 foot probe wire.

9.1.2.1 The exploring coil method has the advantage of not requiring a conductive path to earth as does the probe wire method; so less time is required to set up and complete measurements at a given location. Since the probe coil has no conductive connection to earth it is less subject to error than a probe wire from ground voltages resulting from other sources at the fundamental and lower harmonic frequencies.

9.1.2.2 The exploring coil sensitivity is approximately the same as that of measurements made with a ten foot probe wire, resulting in adequate accuracy for noise investigations.

9.1.3 Earth return current can also be measured with a probe wire. This method involves measurement of the open circuit voltage induced in a wire placed parallel to and directly under a power line, with a conductive path to earth at the far end. The length most frequently used is one hundred feet although probe wires as long as five hundred feet are sometimes used to measure the effects (not ground return current) of High Voltage Direct Current transmission lines.

9.1.3.1 Probe wire sensitivity is better than that of an exploring coil. This added sensitivity does not contribute much to a noise investigation, when the time required to set up and complete measurements at a given location is considered. The one hundred foot, or longer, wire must be laid on the ground parallel to the power line and a ground rod must be driven at each end. Probe wire measurements are subject to serious error at the fundamental and lower harmonic frequencies due to the presence of ground voltages from other nearby sources.

9.1.3.2 Conversion factors for use with a 100 foot probe wire in Table VI will differ from other published values. The correct probe wire equation used for calculating mutual inductance (M) is $M=14 \text{ Log } (400 + H)/H)$ For years $M=14 \log ((400-H)/H)$ has been used. The minus sign appears to be in error.

9.2 Exploring coil measurement of power system earth return current will be best understood if individual frequency components of a complex power system waveform are considered. Exploring coil testing involves measurement of the induced voltage across the coil terminals with a spectrum analyzer having a high impedance input (100,000 ohms).

9.2.1 The coil voltage at any single frequency at a relative short distance from a long power line having an earth return current is given by:

$$(V_f) = \frac{4\pi \times 10^{-7}\ NAf\ (I_f) \times 0.3048}{D}$$

Where: (V_f) = Volts across the terminals of the coil at frequency f
N = Number of turns on coil
A = Area of coil in square feet (Air core coil)
f = Frequency in Hertz
(I_f) = Earth return current of power system at frequency f in amperes.
D = Distance from geometric mean of power conductors to center of coil in feet
0.3048 = Conversion factor for feet to meters.

9.2.2 For an example we shall consider an exploring coil with 850 turns and an area of 0.7969 square feet similar to one now available. Calculations for coils of different physical dimensions would be completed in the same manner. Substituting values into the equation of Paragraph 9.2.1 gives:

$$(V_f) = \frac{4\pi \times 10^{-7}\ (850)\ (0.7969)\ (0.3048)\ f\ (I_f) = 2.5945 \times 10^{-4} f\ (I_f)}{D}$$

9.2.2.1 Then, at any single frequency the earth return current is given as:

$$(I_f) = \frac{(V_f)\ D}{2.5945 \times 10^{-4}\ f}$$

9.2.2.2 Some spectrum analyzers provide readings of the voltage magnitude in dBrn and a conversion to volts is necessary. The reference voltage for 0dBrn is 24.5×10^{-6} volts; so:

$$(V_f) = \left(\log^{-1} \frac{(V_f)\ \text{dBrn}}{20}\right)\ 24.5 \times 10^{-6}$$

9.2.2.3 Substituting for (V_f) in the equation of Paragraph 9.2.2.1 gives:

$$(If) = \frac{(\log^{-1}((V_f)\text{dBrn}/20))\ 24.5 \times 10^{-6} D}{2.5945 \times 10^{-4}\ f} = \frac{(\log^{-1}((V_f)\ \text{dBrn}/20))D}{10.5898f}$$

9.2.2.4 If results in (I_f) dBA (decibel Amperes) are desired the equation of Paragraph 9.2.2.3 may be re-written accounting for the 20 log f values from Figure 13 and 20 log D correction factor from Figure 14, as follows:

$$(I_f)\ \text{dBA} = (V_f)\ \text{dBrn} - 20.5 + 20 \log D - 20 \log f$$

9.2.2.5 And to find the earth return current in amperes at any single frequency:

$$(I_f) = \log^{-1} ((I_f)\ dBA/20)$$

9.2.2.6 The magnitude of power system earth return current at any single harmonic frequency may be calculated by substituting exploring coil measurement data into the equation in Paragraph 9.2.2.3. The nomograph shown in Figure 15 has been developed based on this equation for determination of single frequency earth return currents.

9.2.3 The equation of Paragraph 9.2.2.3 cannot be used for calculation of the <u>total</u> earth return current from the recorded results of a single broad band measurement. There is a frequency term in the equation which must be eliminated before a broad band calculation can be made.

9.2.3.1 One way of eliminating the frequency term is by use of 20/f weighting. 20/f weighting is given by:

$$(V_f)\ dBrn\ 20/f = (V_f)\ dBrn + 20 \log (20/f)$$

9.2.3.2 Substituting this in the equation of 9.2.2.4 gives:

$$(I_f)\ dBA = (V_f)\ dBrn_{20/f} -20.5 -20 \log (20/f) -20 \log f + 20 \log D$$

$$= (V_f)\ dBrn_{20/f} -20.5 -20 \log 20 + 20 \log D$$

9.2.3.3 Since 20 log 20 = 26 the equation of Paragraph 9.3.2 becomes:

$$(I_f)\ dBA = (V_f)\ dBrn_{20/f} -46.5 + 20 \log D$$

$$(I_f)\ dBA = (V_f)\ dBrn_{20/f} -40 + (20 \log D -6.5)$$

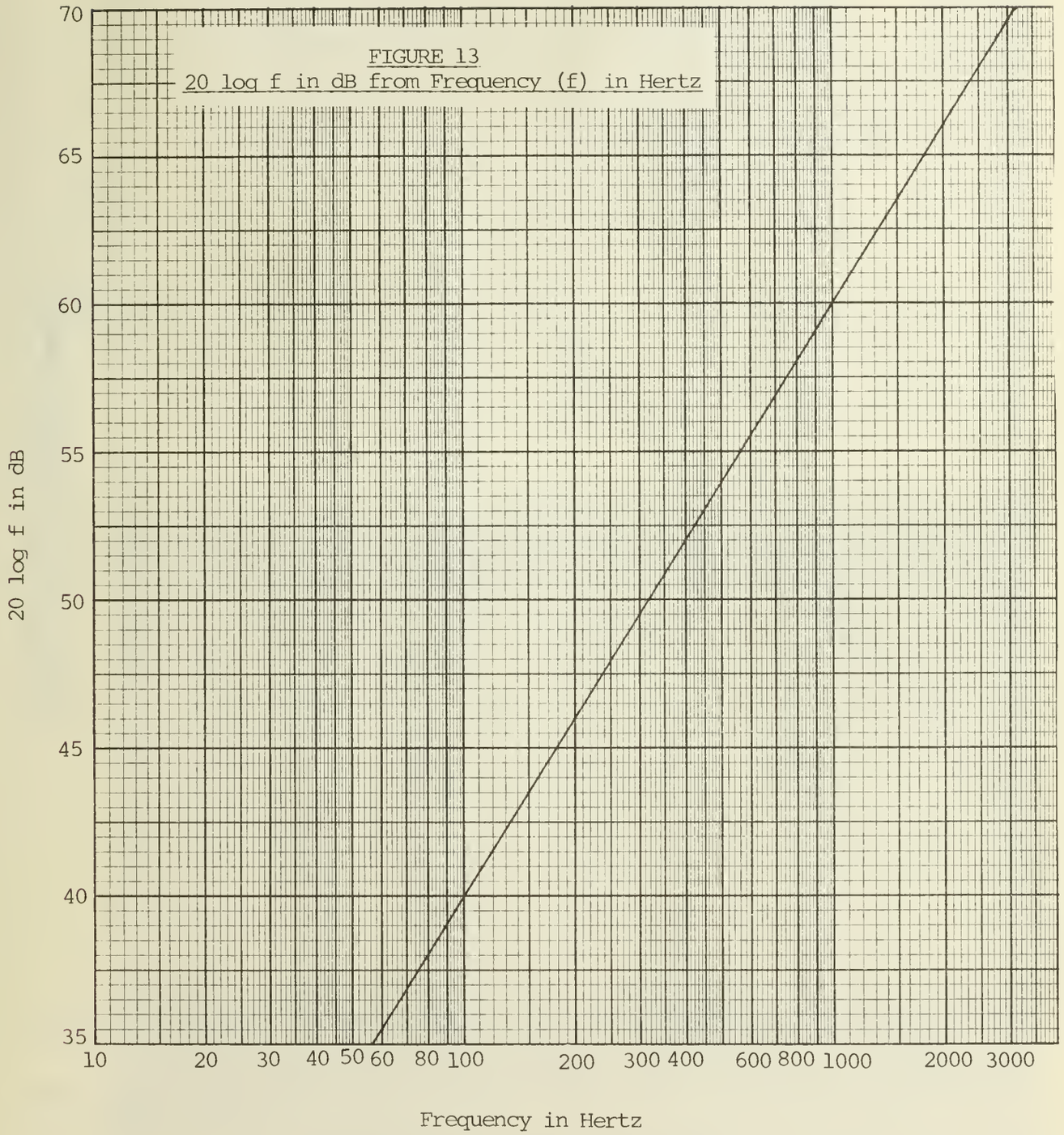
9.2.3.4 This equation contains no frequency term. Use of the 20/f weighting has cancelled it out. Since the correction factor, 20 log D -46.5, applies equally to all harmonics, it must also apply to the root-sum-square total. Therefore, the equation in Paragraph 9.2.3.3 can be re-written without the frequency subscripts:

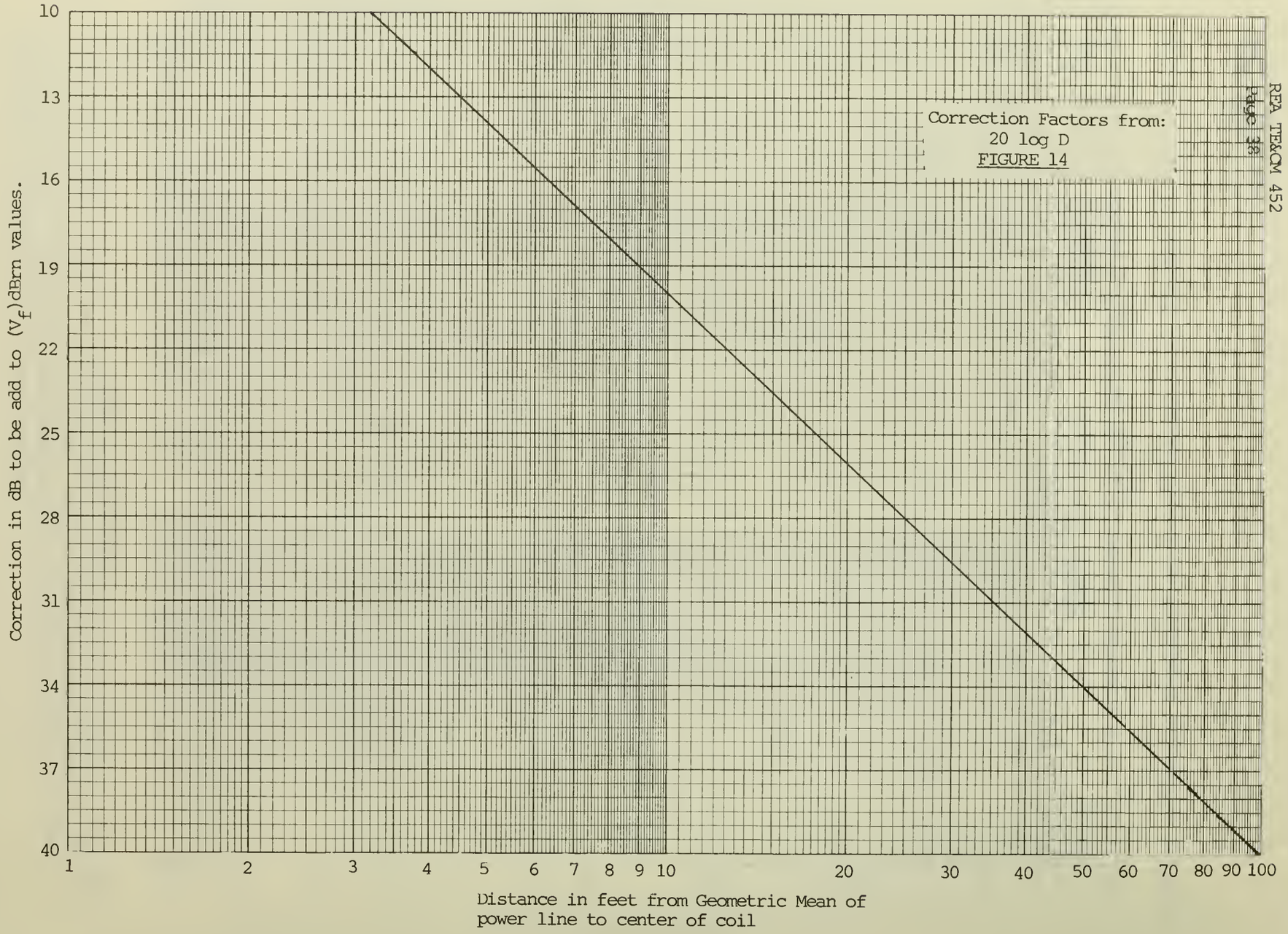
$$I_{dBA} = VdBrn_{20/f} -40 + (20 \log D -6.5)$$

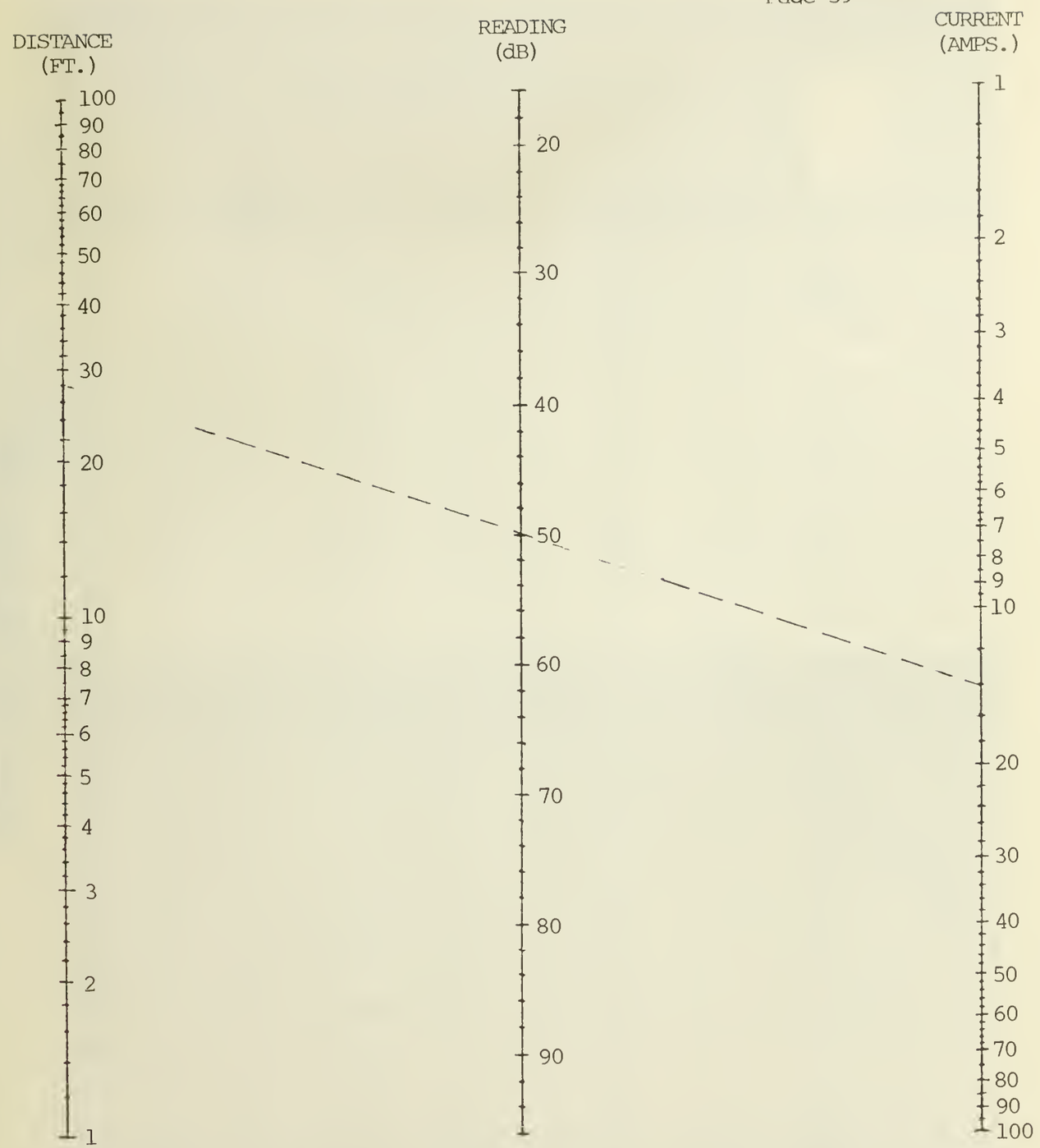
9.2.3.5 With this equation a spectrum analyzer equipped with a 20/f weighted filter can be used for single frequency measurements and for a single broadband measurement of the total (unweighted) earth return current. The correction factor (20 log D -6.5) may be obtained from either Figure 16 or Table IV.

9.2.3.6 When a spectrum analyzer without a 20/f filter is used the (V_f) dBrn 20/f value for each frequency can be calculated by the equation in Paragraph 9.2.3.1. The 20/f weighting factors are given in Table V. The equation in Paragraph 9.2.3.4 now becomes:

FIGURE 13
20 log f in dB from Frequency (f) in Hertz




Correction Factors from:
20 log D
FIGURE 14
Correction in dB to be add to (V_f)dBrn values.
10
13
16
19
22
25
28
31
34
37
40
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
Distance in feet from Geometric Mean of
power line to center of coil



Example: Distance between center of probe coil and geometric center of power phasewire-neutralwire configuration = 28 ft. Meter reading = 50 dB. Ground return current = 14 amperes.

Note: Divide ground return current by order of harmonic for other than 60 Hz.

Set function switch to BRDG 600

Courtesy of Wilcom Products, Inc.

FIGURE 15
SINGLE FREQUENCY EARTH RETURN CURRENT

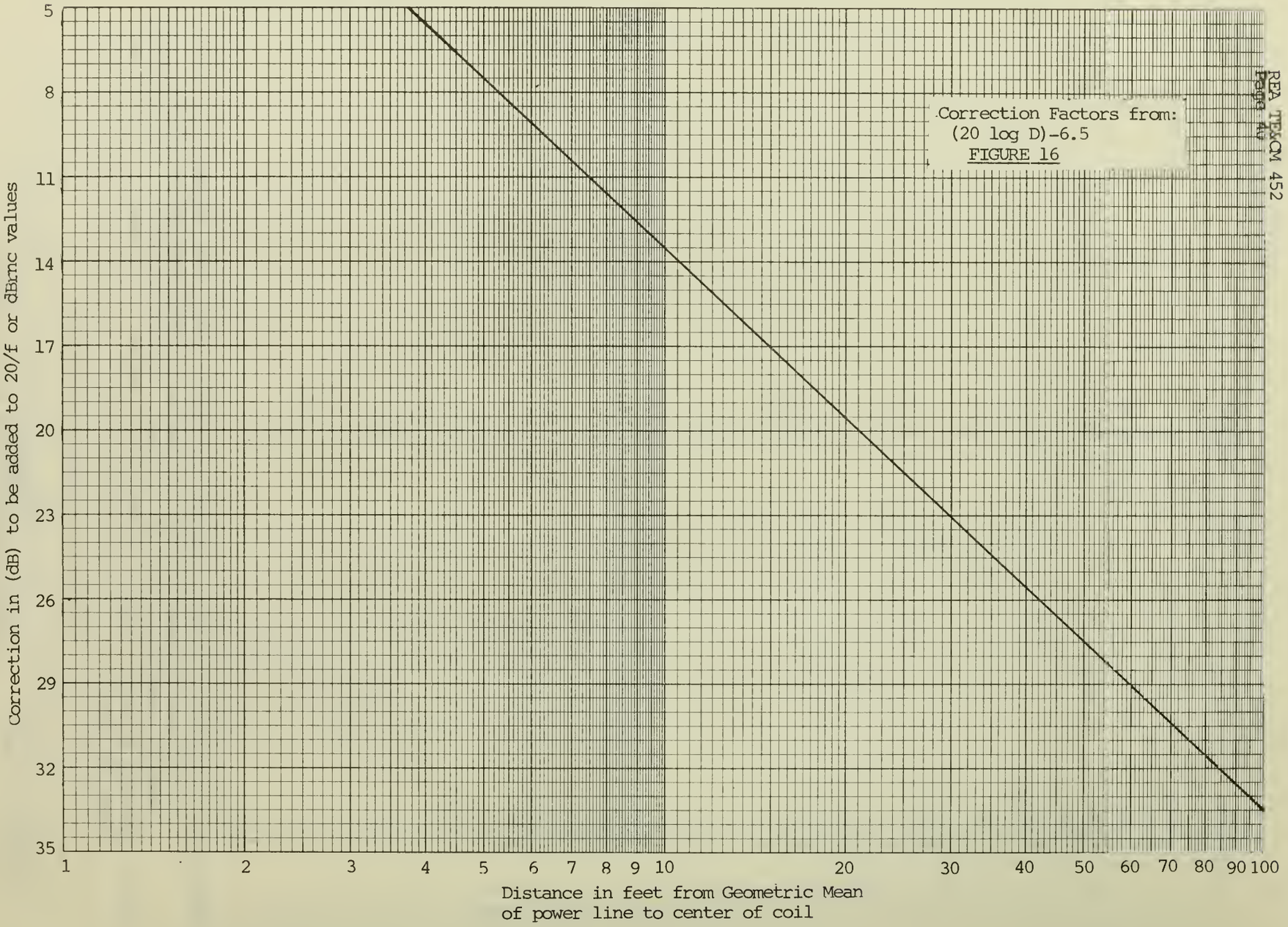

Correction Factors from:
(20 log D)-6.5
FIGURE 16
Correction in (dB) to be added to 20/f or dBrnc values
5
8
11
14
17
20
23
26
29
32
35
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
Distance in feet from Geometric Mean
of power line to center of coil

TABLE V

POWER HARMONIC 20/f WEIGHTING FACTORS

FREQUENCY	60 HERTZ HARMONIC	RATIO 20/f	20/f FACTOR dB	FREQUENCY	50 HERTZ HARMONIC	RATIO 20/f	20/f FACTOR dB
60	1	0.3330	- 9.5	1500	25	0.0133	-37.5
120	2	0.1670	-15.6	1620	27	0.0123	-38.2
180	3	0.1110	-19.1	1740	29	0.0115	-38.8
240	4	0.0833	-21.6	1800	30	0.0111	-39.1
300	5	0.0667	-23.5	1860	31	0.0108	-39.4
360	6	0.0556	-25.1	1980	33	0.0101	-40.0
420	7	0.0476	-26.4	2100	35	0.00952	-40.4
480	8	0.0417	-27.6	2220	37	0.00901	-40.9
540	9	0.0370	-28.6	2340	39	0.00855	-41.4
600	10	0.0333	-29.5	2460	41	0.00813	-41.8
660	11	0.0303	-30.4	2580	43	0.00775	-42.2
720	12	0.0278	-31.1	2700	45	0.00741	-42.6
780	13	0.0256	-31.8	2820	47	0.00709	-43.0
840	14	0.0238	-32.5	2940	49	0.00680	-43.3
900	15	0.0222	-33.1	3000	50	0.00667	-43.5
960	16	0.0208	-33.6	3060	51	0.00654	-43.7
1020	17	0.0196	-34.2	3180	53	0.00629	-44.0
1080	18	0.0185	-34.6	3300	55	0.00606	-44.3
1140	19	0.0175	-35.1	3480	57	0.00575	-44.8
1200	20	0.0167	-35.6	3540	59	0.00565	-45.0
1260	21	0.0159	-36.0	4500	75	0.00444	-47.0
1380	23	0.0145	-36.8				

20/f dB = 20 log 20/f

$$dBA = 10 \log \left[\Sigma \left(\log^{-1} \frac{(Vf)\, dBrn\ 20/f}{10} \right) \right] -40 + (20 \log D - 6.5)$$

9.2.3.7 Amperes earth return current is given by:

$$I = \log^{-1} (I_{dBA}/20)$$

9.2.4 A detailed discussion of how to perform exploring coil measurements of power system earth return currents and the analysis of recorded results is presented in TE&CM Section 452.2.

GEOMETRIC MEAN HEIGHT OF POWER LINE ABOVE CENTER OF COIL

20'	25'	30'	35'	40'	45'	50'	55'	60'
19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

CORRECTION FACTOR = (20 log -6.5)

CORRECTION FACTORS - TABLE IV

9.2.5 I·T can be calculated at each individual frequency by multiplying the current for the frequency from the equation in Paragraph 8.2.3.7 by the TIF factor from Table III. There is an easier way of determining the I·T value using the C-message weighting setting of the spectrum analyzer. With C-message weighting the reading is given by:

$$(V_f)\ dBrnc = (V_f)\ dBrn + 20 \log C_f$$

9.2.5.1 Substituting this in the equation of Paragraph 9.2.2.4 gives:

$$(I_f)\ dBA = (V_f)\ dBrnc -20.5 -20 \log C_f -20 \log f + 20 \log D$$

9.2.5.2 TIF weighted value is obtained by multiplying both sides of the equation by W_f:

$$(I_f \cdot W_f)\ dBA = (V_f)\ dBrnc -20.5 -20 \log C_f + 20 \log W_f -20 \log f + 20 \log D$$

9.2.5.3 From Paragraph 8:

$$W_f = 5f\ C_f$$

9.2.5.4 Substituting this in the equation of Paragraph 9.2.5.2 gives:

$$(I_f \cdot W_f)\ dBA = (V_f)\ dBrnc - 20.5 - 20 \log Cf + 20 \log 5fC_f - 20 \log f + 20 \log D$$

$$= (V_f)\ dBrnc - 20.5 + 20 \log 5 + 20 \log D$$

9.2.5.5 Since 20 log 5 = 14 the equation of Paragraph 9.2.5.4 becomes:

$$(I_f \cdot W_f)\ dBA = dBrnc + (20 \log D - 6.5)$$

9.2.5.6 Like the equation in Paragraph 9.2.3.3 this equation contains no frequency term. This time a combination has been used of C-message weighting and frequency-proportional coupling in Paragraph 9.2.2.4 to obtain TIF weighting, with a correction factor which applies equally well to all TIF weighted harmonics and, therefore, to the root-sum-square total as well. Therefore, the equation in Paragraph 9.2.5.5 can be rewritten without the frequency subscripts:

$$(I \cdot T)\ dBA = VdBrnc + (20 \log D - 6.5)$$

9.2.5.7 With this equation a spectrum analyzer equipped with a C-message filter can be used for single frequency measurements and for a single broadband measurement of the total I·T. The correction factor (20 log D -6.5) may be obtained from either Figure 16 or Table IV.

9.2.5.8 When a spectrum analyzer without a C-message filter is used the (V_f) dBrnc value for each frequency can be calculated by the equation in Paragraph 9.2.5. C-message factors (C_f) are given in Table II. The equation in Paragraph 9.2.5.6 now becomes:

$$(I \cdot T)\ dBA = 10 \log \left[\Sigma \left(\log^{-1} \frac{(V_f\ dBrnc)}{10} \right) \right] + (20 \log D - 6.5)$$

9.2.5.9 I·T is given by:

$$I \cdot T = \log^{-1} (I \cdot T)\ dBA/20)$$

9.2.6 A detailed discussion of how to perform exploring coil measurements of power system I·T and the analysis of recorded results is presented in TE&CM Section 452.2.

9.2.7 Since TIF is the ratio of the RSS weighted amplitudes to the RMS current amplitudes (unweighted), from the equation in Paragraphs 9.2.3.4 and 9.2.5.6, we have:

$$T = \log^{-1} ((VdBrnc - VdBrn\ 20/f + 40)/20)$$

9.3 Probe wire measurements of power system earth return current will be best understood if the individual frequency components of a complex power system waveform are considered. The use of a spectrum analyzer having a high impedance input (> 100,000 ohms) is assumed. Thus, the input impedance is high compared to the likely ground resistance between the two electrodes and the induced voltage may be read directly.

9.3.1 The voltage at any single frequency induced in a probe wire at a relative short distance from a long power line having an earth return current is given by:

$$(V_f) = 2\pi\ f\ M\ (I_f)$$

Where: (V_f) = Volts induced in probe wire at frequency f
f = Frequency in Hertz
(I_f) = Earth return current of power system at frequency f
M_f = Mutual inductance between the probe wire and average of all power-line conductors, given by:

$$M = 0.14 \times 10^{-6} \ell \log \left(\frac{400 + D}{D}\right) \text{ Henries}$$

ℓ = Length of probe wire in feet
D = Distance from geometric mean of power conductors to probe wire

9.3.2 At any single frequency the earth return current is given as:

$$(I_f) = (V_f) \ / \ 2\pi fM$$

9.3.2.1 By expressing the current and voltage in dB relative to one ampere and one volt, respectively, the equation can be written:

$$(I_f)\ \text{dBA} = (V_f)\ \text{dBV} - 20 \log 2\ \pi\ f - 20 \log M$$

9.3.2.2 Since most spectrum analyzers provide levels in dBrn, a conversion to dBV is necessary. The zero dBrn reference level is 24.5 microvolts, giving:

$$V_{dBV} = V_{dBrn} + 20 \log (24.5 \times 10^{-6})$$
$$= \text{VdBrn} - 92.2$$

9.3.2.3 Combining the equation in Paragraph 9.3.2.1 with the one in Paragraph 9.3.2.2 gives:

$$(I_f)\ \text{dBA} = (V_f)\ \text{dBrn} - 92.2 - 20 \log 2\ \pi\ f - 20 \log M$$

9.3.2.4 And to find the amperes earth return current at any single frequency:

$$(I_f) = \log^{-1} ((I_f)\ \text{dBA}/20)$$

9.3.3 The magnitude of power system earth return currents at any harmonic frequency may be calculated by the equation in Paragraph 9.3.2.3, substituting results of probe wire measurements. It cannot be used for calculation of <u>total</u> earth return current from results of a single broadband measurement. The frequency term in the equation must be eliminated before a broadband calculation can be made.

9.3.3.1 A method of eliminating the frequency term is by use of 20/f weighting. 20/f weighting is given by:

$$(V_f)\ \text{dBrn 20/f} = (V_f)\ \text{dBrn} + 20 \log (20/f)$$

9.3.3.2 Combining the equation in Paragraph 9.3.2.3 and the one in Paragraph 9.3.3.1 gives:

$$(I_f)\ \text{dBA} = (V_f)\ \text{dBrn}_{20/f} - 20 \log (20/f) - 92.2 - 20 \log 2\pi f - 20 \log M$$

$$= (V_f)\ \text{dBrn}_{20/f} - 20 \log 40\pi - 92.2 - 20 \log M$$

9.3.3.3 Since 20 log 40π = 42 the equation of Paragraph 9.3.3.2 becomes:

$$(I_f)\ \text{dBA} = (V_f)\ \text{dBrn 20/f} - 134.2 - 20 \log M$$

or more conveniently:

$$(I_f)\ \text{dBA} = (V_f)\ \text{dBrn 20/f} - 40 - (20 \log M + 94.2)$$

9.3.3.4 With this equation a spectrum analyzer equipped with a 20/f weighted filter can be used to determine the power line earth return current component at any single frequency in dB above one ampere. Values of the correction factor (20 log M + 94.2) for a 100-foot probe wire at various power line heights are shown in Table VI.

9.3.3.5 The equation in Paragraph 9.3.3.3 contains no frequency term. Use of the 20/f weighting has cancelled it out. Since the correction factor (20 log M + 134.2), applies equally to all harmonics, it must also apply to the root-sum-square total. The equation can, therefore, be written without the frequency subscripts:

$$I_{dBA} = V_{dBrn\ 20_f} - 40 - (20 \log M + 94.2)$$

9.3.3.6 Thus a spectrum analyzer, with 20/f weighting, may be used for a single broadband measurement of the total (unweighted) earth return current as well as that for single frequencies. The Correction Factors may be obtained from Table IV.

9.3.3.7 When a spectrum analyzer without a 20/f filter is used, the (VF) dBrn 20/f values for each frequency can be calculated by the equation in Paragraph 9.3.3.1. The 20/f weighting factors are given in Table V. The equation in Paragraph 9.3.3.5 now becomes:

$$I_{dBA} = 10 \log \left[\Sigma \left(\log^{-1} \frac{(V_f)\ \text{dBrn 20/f}}{10} \right) \right] - 40 - (20 \log M + 94.2)$$

TABLE VI

CORRECTION FACTORS (20 LOG M + 94.2) FOR 100 FOOT PROBE WIRE

D*	FACTOR dB	D*	FACTOR dB	D*	FACTOR dB
11	1.05	28	-1.41	45	-2.92
12	0.85	29	-1.51	46	-2.99
13	0.66	30	-1.62	47	-3.07
14	0.47	31	-1.72	48	-3.14
15	0.30	32	-1.81	49	-3.21
16	0.14	33	-1.91	50	-3.28
17	-0.02	34	-2.00	51	-3.35
18	-0.17	35	-2.09	52	-3.42
19	-0.31	36	-2.18	53	-3.49
20	-0.45	37	-2.27	54	-3.56
21	-0.58	38	-2.36	55	-3.62
22	-0.71	39	-2.44	56	-3.69
23	-0.84	40	-2.53	57	-3.75
24	-0.96	41	-2.61	58	-3.82
25	-1.08	42	-2.68	59	-3.88
26	-1.19	43	-2.77	60	-3.94
27	-1.30	44	-2.84		

D = Height of power line above probe wire in feet.

9.3.3.8 Amperes earth return current is given by:

$$I = \log^{-1} (I_{dBA}/20)$$

9.3.4 I·T can be calculated at each individual frequency by multiplying the current for the frequency from the equation in Paragraph 9.3.3.5 by the TIF factor from Table III. There is an easier way of determining the I·T value using the C-message weighting setting of the spectrum analyzer. With C-message weighting the reading is given by:

$$(V_f)\ dBrnc = (V_f)\ dBrn + 20 \log C_f$$

9.3.4.1 Substituting this in the equation of Paragraph 9.3.2.9 gives:

$$(I_f)\ dBA = (V_f)\ dBrnc - 20 \log C_f - 92.2 - 20 \log 2\pi f - 20 \log M$$

9.3.4.2 The TIF weighted value is obtained by multiplying both sides by W_f:

$$(I_f \cdot W_f)\ dBA = (V_f)\ dBrnc - 92.2 - 20 \log C_f + 20 \log W_f - 20 \log 2\pi f - 20 \log M$$

9.3.4.3 Substituting the value for W_f from Paragraph 9.2.5.3 gives:

$$(I_f \cdot W_f)\ dBA = (V_f)\ dBnc - 92.2 - 20 \log C_f + 20 \log 5fC_f - 20 \log 2\pi f - 20 \log M = (V_f)\ dBrnc - 92.2 + 20 \log 5/2\pi - 20 \log M$$

9.3.4.4 Since $20 \log 5/2\pi = 2.0$ the equation in Paragraph 9.3.4.3 becomes:

$$(I_f \cdot W_f)\ dBA = (V_f)\ dBrnc - (20 \log M + 94.2)$$

9.3.4.5 With this equation, a spectrum analyzer with C-message weighting can be used to determine the earth return I·T contribution of each harmonic frequency in dB above one weighted ampere. Values of the correction factor (20 log M + 94.2) for a 100 foot probe wire at various power line heights are shown in Table VI.

9.3.4.6 The equation in Paragraph 9.3.4.4 contains no frequency term. This time a combination has been used of C-message weighting and frequency proportional coupling in Paragraph 9.3.1 to obtain TIF weighting with a correction factor which applies equally well to all TIF weighted harmonics and, therefore, to the root-sum-square total as well. The equation can, therefore, be written without the frequency subscripts:

$$(I \cdot T)\ dBA = VdBrnc - (20 \log M + 94.2)$$

9.3.4.7 Again, the spectrum analyzer can be used, this time with C-message weighting, for a single broadband measurement of the earth return I·T as well as for single frequencies. The correction factors may be obtained from Table VI.

9.3.4.8 When a spectrum analyzer without a C-message filter is used the (V_f) dBrnc value for each frequency can be calculated by the equation in Paragraph 9.3.4 C-message factors (C_f) are given in Table II. The equation in Paragraph 9.3.4.6 now becomes:

$$(I \cdot T)\ dBA = 10 \log \left[\Sigma \left(\log^{-1} \frac{(V_f)\ dBrnc}{10} \right) \right] - (20 \log M + 94.2)$$

9.3.4.9 Numerical I·T is given by:

$$I \cdot T = \log^{-1} ((I \cdot T)\ dBA/20)$$

9.3.5 A detailed discussion of how to perform probe wire measurements of power system earth return I and I·T with analysis of recorded results is presented in TE&CM Section 452.3.

9.3.6 Since TIF is the ratio of weighted to unweighted amplitudes, from the equations in Paragraphs 9.3.3.5 and 9.3.4.6, we have:

$$T = \log^{-1} ((VdBrnc - VdBrn\ 20/f + 40)/20)$$

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TELEPHONE CABLE PAIR HARMONIC ANALYSIS

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DEPOSITORY
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9.	Example-Matrix-Second Measurement	18

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to provide an understanding of cable pair power influence harmonic analysis during noise investigations.

1.2 This section is issued to present techniques for the measurement and analysis of the harmonic content of the noise-to-ground or power influence on a cable pair. It is a specialized technique for application where noise investigation procedures performed by crafts people have failed to find a solution to the problem. The technique is a diagnostic tool recommended as the initial action where a need for specialized procedures has been established. Study of the recorded results from these measurements may appear to provide sufficient information to determine appropriate corrective action. Such action should not be initiated without additional measurements to confirm the analysis. Power influence analysis should be utilized to determine the direction for subsequent investigation thus reducing the time required for completing other advanced measurement procedures.

1.3 A telephone circuit located parallel to a power line can be compared to a probe wire. Probe wire measurements are completed to determine the efficiency of a power system through the magnitude of earth return currents. While the magnitude of earth return current cannot be determined through measurement of the longitudinal induced harmonic voltage

on a telephone circuit valuable information can be obtained relative to power system performance. It has been noted that the harmonic variation measured with a probe wire located beneath a power line will be in close correlation to longitudinal harmonic voltage measurements on a cable pair located parallel to the same power line. Since many power line conditions which can result in telephone system interference have a distinct harmonic pattern or signature they can be identified by measuring the longitudinal harmonic voltage to ground on a cable pair.

2. MEASUREMENT

2.1 Data for analysis is obtained by measuring and recording the noise-to-ground (Ng) or power influence (PI) on a noisy cable pair. For a discussion of noise-to-ground and power influence refer to TE&CM Section 451, Paragraph 12. All harmonic frequencies of the power system fundamental frequency from the first through the forty seventh (60 through 2820 Hertz, inclusive) should be measured and recorded on a data form for power influence analysis.

2.1.1 A sample data form for power influence analysis is shown in Figure 1. This form provides a space for recording the power influence level in dBrn for the harmonic frequencies from 60 through 2820 Hertz. Column 3 lists the average noise levels from a loop study. While the levels should be measured and recorded for all the listed harmonics levels below those shown in column 3 are disregarded during the analysis.

2.1.2 There will be occasions where a frequency other than a harmonic of the fundamental power line frequency will be present as a component of the noise to ground. The level and frequency of these other components should also be recorded.

2.2 Measurements may be made at a subscriber station protector or at either end of an idle pair in a noisy cable. The subscriber station protector is preferred since there should be a good low resistance ground available for connection to the test set.

2.2.1 Where measurements are made at the field end of an idle cable pair there should be a ground rod (with low resistance to earth) or multigrounded neutral connection for ground reference rather than the cable shield alone. The pair is shorted and grounded at the central office.

2.2.2 When an idle pair is measured at the central office the central office ground is available for connection to the test set. The cable pair is shorted and grounded to a low resistance ground such a multi-grounded neutral at the field end. This method is recommended when several pairs of different length are to be measured which would require setting up at several field locations.

2.3 When measurements are to be made with a spectrum analyzer which has the capability of functioning as a noise measuring set the tip and ring conductors of the cable pair or drop are connected to the appropriate terminals of the test set as shown in Figure 2. A connection

HARMONIC ANALYSIS DATA SHEET

REA TE&CM 452.1

Company _____ Date _____

Exchange _____ Time _____

Route _____ Pair _____

Tested By _____

Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)	Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)
1	60		115	37	2220		37
2	120		106	38	2280		36
3	180		97	39	2380		35
4	240		92	40	2400		35
5	300		83	41	2460		34
6	360		80	42	2520		34
7	420		77	43	2580		34
8	480		77	44	2640		34
9	540		77	45	2700		34
10	600		70	46	2760		34
11	660		65	47	2820		34
12	720		61				
13	780		58				
14	840		57				
15	900		55				
16	960		51				
17	1020		48				
18	1080		47				
19	1140		46				
20	1200		45				
21	1260		44				
22	1320		43				
23	1380		43				
24	1440		42				
25	1500		42				
26	1560		41				
27	1620		41				
28	1680		41				
29	1740		41				
30	1800		40				
31	1860		39				
32	1920		39				
33	1980		38				
34	2040		38				
35	2100		37				
36	2160		37				

Overall Noise Measurement

3kHz.

Power Influence (Ng+40) _____ dBrn

Circuit Noise (Nm) _____ dBrn

Balance _____ dB

C-Msg.

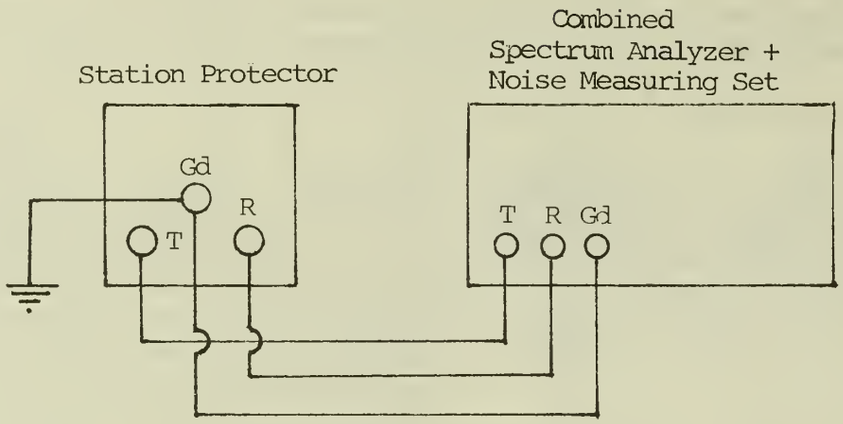
Power Influence (Ng+40) _____ dBrnc

Circuit Noise (Nm) _____ dBrnc

Balance _____ dB

FIGURE 1

is established between the ground terminal of the test set and a low resistance ground such as the ground terminal of a subscriber station protector. (See Paragraph 2.2).



SPECTRUM ANALYZER + NOISE MEASURING SET CONNECTIONS

FIGURE 2

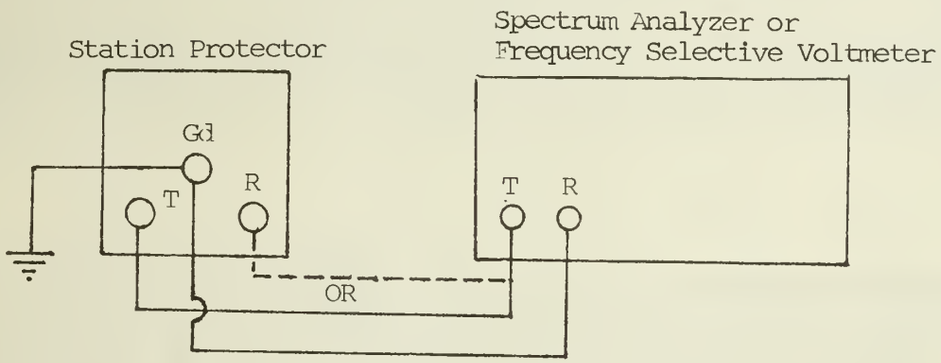
2.3.1 Set the spectrum analyzer to measure noise-to-ground. The weighting switch should be set for 3kHz Flat weighting. The test set should be switched to function as a frequency selective device rather than a noise measuring set.

2.3.2 Where measurements are being made on a working pair first dial the quiet termination and then switch in the holding coil. When an idle pair is used it is only necessary to short circuit and ground the tip and ring of the pair at the central office MDF.

2.3.3 Set the spectrum analyzer to the desired harmonic frequency and read the magnitude in dBrn. Successively read the magnitude of each harmonic frequency starting at 60 Hertz through 2820 Hertz. Values of power influence should be recorded for harmonics of the 60 Hertz fundamental frequency. See paragraph 2.1. Remember to add 40 dB if measurements are in units of noise-to-ground.

2.3.4 Switch the test set to the noise measuring set mode with C-message weighting, read and record the overall power influence in dBrnc. Then switch to measure noise metallic (Nm), read and record the value. These measurements provide data from which the balance of the cable pair may be determined. See TE&CM Section 451, Paragraph 12.3 for a discussion of balance.

2.4 Where measurements are to be made with a spectrum analyzer or frequency selective voltmeter that does not have noise measuring set capability one input terminal is connected to either the tip or ring conductor of the cable pair or drop as shown in Figure 3. The other terminal is connected to a low resistance ground such as the ground terminal of a subscriber station protector (See Paragraph 2.2). The input circuit of the test set should be high impedance (100,000 ohms or greater). For uniformity purposes only, always connect the ring terminal of the test set to the station ground and the tip terminal to either wire of the cable pair under test.



SPECTRUM ANALYZER CONNECTIONS

FIGURE 3

2.4.1 Read the magnitude of each harmonic frequency in dBm, if possible, starting at 60 Hertz through 2820 Hertz. Values should be recorded in dBrn, for all harmonics of the 60 Hertz fundamental frequency. See paragraph 2.1 DBm plus 90 equals dBrn.

2.4.2 Where the test set meter face does not contain a dBm scale, the readings will be in volts. While a voltage scale has been included in the analysis chart (See Paragraph 3) these values are difficult to plot accurately. It is recommended that voltage magnitudes be converted to dBrn (power influence) before recording. Figure 4 has been prepared for easy conversion. To use, enter the chart at the measured voltage magnitude along the bottom horizontal scale and follow the vertical line from that point to the point it intersects the curve. Read the dBrn value of this point on the appropriate vertical scale.

2.4.3 Since the test set does not have noise measuring set capability it will be necessary to use a conventional noise measuring set to measure the C-message weighted power influence and circuit noise as discussed in Paragraph 2.3.4.

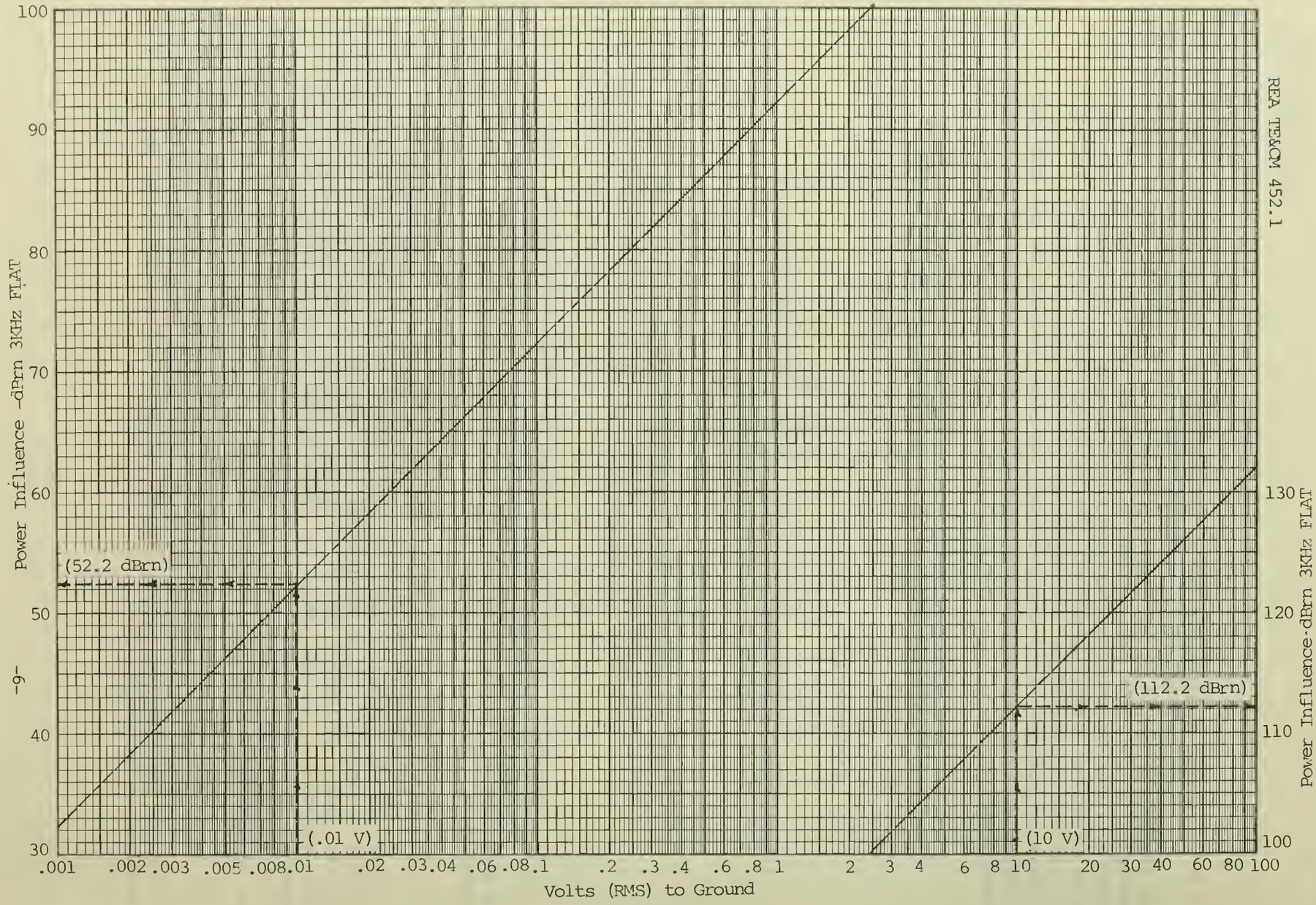


FIGURE 4

CONVERSION CHART

POWER INFLUENCE-dBrn 3 KHz FLAT TO VOLTS TO GROUND

3. ANALYSIS

3.1 The "Cable Pair Harmonic Analysis Matrix" shown in Figure 5 has been developed for graphical analysis of the harmonic content of cable pair power influence. Analysis is accomplished by relating the patterns formed by predominant harmonics to those indicating specific probable sources of noise.

3.1.1 The Sketch of Telephone and Power Facilities area (I) is used to record pertinent information relative to the physical makeup of the two facilities. Prepare a sketch showing the length of exposure, type of communications facility, type of power facility and separations between the two lines. Also include information regarding capacitor bank, voltage regulators, power substation and industrial plant locations. It is advisable to examine the power line beyond the length of actual exposure. Power system components in those areas can have a bearing on telephone system noise. Locations of capacitor banks beyond the ends of the exposure should always be noted.

3.1.2 The Level Graph (II) is based on statistical studies of subscriber loop noise surveys. An average or mean (μ) and upper standard deviation (σ) level (84% are statistically lower) are included for each harmonic frequency. A recorded value above the σ level ( ) is considered excessive. Recorded values falling between the σ and μ ( ) levels are in the marginal range. All values below the μ level are considered to be acceptable. Post the recorded results of measurements from the harmonic analysis data sheet (See paragraph 2.1.1) to the level graph. Include all harmonic frequencies with levels exceeding the mean values listed in column 3 of the data form. Plot the values from the initial measurement with an x. Results from subsequent measurements to determine the effectiveness of corrective actions are plotted with an ⊙ and ⊡ respectively.

3.1.3 The Correlation Matrix (III) is based on analysis of case studies and descriptions of harmonic producing components. Attempt by inspection to identify the closest match between the excessive and/or marginal harmonic levels plotted in the "Level Graph" and the circles in the matrix. Although perfect matches seldom occur, reasonable matches can often by identified and related to one or more probable sources. Noise problems are often associated with multiple power system sources which must be identified and corrected one at a time. (See paragraph 3.2 for a discussion of the analysis procedure).

3.1.4 The Probable Sources (IV) list is composed of the most common sources of power induced interference in telephone systems. They are related to the distinctive harmonic pattern associated with each specific source in the "Correlation Matrix". In some cases there are additional confirmation tests which may be completed by telephone company personnel prior to contacting the power company. In other cases measurements to verify the exact sources(s) and cause(s) must be made jointly with power company personnel.

3.1.5 Refer to the Notes (V) when making any analysis. Information included in the notes can be valuable in determining the source of noise problem.

CABLE PAIR HARMONIC ANALYSIS MATRIX

(For problems not related to circuit balance, shield continuity or grounding)

Company _____ Date _____

Exchange _____ Time _____

Route _____ Pair _____

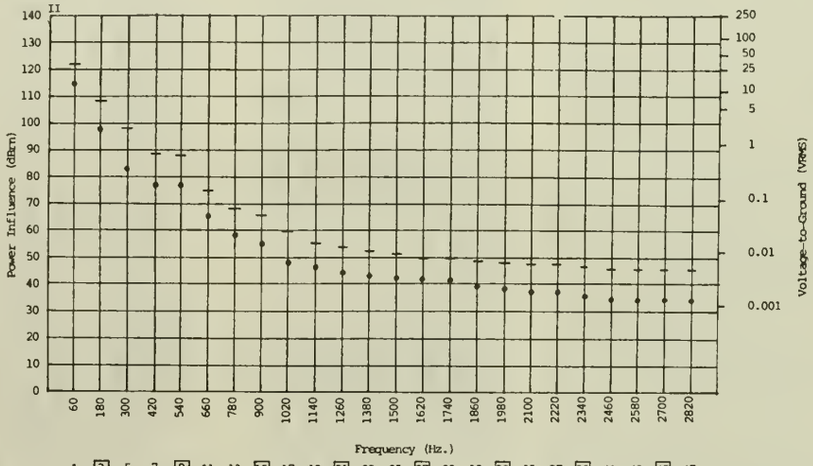
Tested by _____

LEGEND
- • Mean (μ)
- ⊢ μ ± δ
- × First Test
- ⊙ Second Test
- ⊡ Third Test

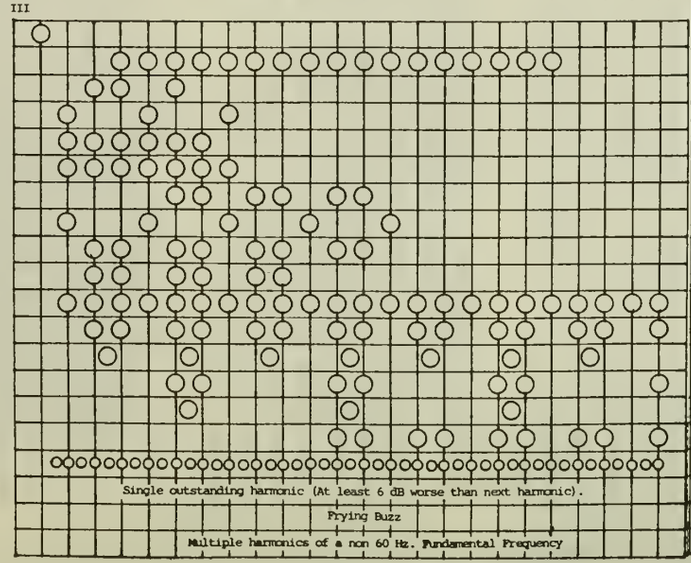
I. SKETCH OF TELEPHONE AND POWER FACILITIES

Show: Mileage of both to nearest 1/10 mile; Type telephone facility, e.g. aerial & buried cable, open wire, etc.; Type power exposure, number of phases, Delta, Y-MGN, etc., capacitor bank locations, etc.

II



III


Single outstanding harmonic (At least 6 dB worse than next harmonic).
Frying Buzz
Multiple harmonics of a non 60 Hz. Fundamental Frequency

V

1. Sometimes accompanied by carbon block dusting or shorting. May also produce gas tube firing.
2. For long single exposures, a 1:1 power transformer may provide a solution.
3. Sometimes caused by open fuses protecting capacitors connected to one or two phase wires.
4. Each higher harmonic deviating more from the mean (assumes that all harmonics are at the same level). This is not always the case.
5. The 420 or 660 Hz. harmonic frequency may not appear predominately.
6. Usually occurs below the 15th harmonic. Can often be improved by relocating capacitors nearer to substation, installation of resonant shunt in capacitor bank ground wire or using a nongrounded (floating) capacitor configuration.
7. Seldom produces harmonics above the 13th.
8. Usually occurs during periods of low power demand.
9. Ninth harmonic (540 Hz) will often be predominant.
10. A high thurd harmonic may be due to ballast operated gaseous-discharge lamps (flourescent, mercury varpor, etc.).
11. Usually one (or two adjacent) sets of odd, nontriple harmonics.
12. Frequencies may not be exact harmonics of 60 Hz. which may be due to "slot" harmonics from induction motors. If a ripple (120 Hz. - from the resonance of two adjacent slot frequencies) is present, it may be caused by slot effects of "rolating field" generators.
13. One adjacent pair of nontriple harmonics is sufficient to suggest rectifier problems.
14. Usually occurs during periods of peak power demand.

IV	PROBABLE SOURCE	(V) SEE NOTES
1	Poorly balanced 3Ø power line, long exposure to single or 2Ø power circuits, or one or two capacitors of a 3Ø capacitor bank not functioning	1, 2, 3
2	Open cable shield	4
3	Malfunctioning capacitor bank(s)	5
4	Circuit resonance. Usually aggravated by capacitor bank(s)	6, 10
5	Exciting currents of silicon iron core distribution transformers. Can be aggravated by circuit resonance due to shunt capacitors	7
6	Overexcited power transformers	8, 9
7	Defective power step-down transformer	
8	Grounded 3Ø transformer, transformer either with an inadequate or without a tertiary winding, or a grounded-Y autotransformer	10
9	Balanced harmonics from generator, synchronous motor or condenser	11, 12
10	SCR control devices	
11	Open lamp on series street lighting circuit using individual transformers	
12	AC side of 6Ø rectifier or SCR control devices	13
13	DC side of 6Ø rectifier	
14	AC side of 6Ø rectifier	13
15	DC side of 12Ø rectifier	
16	AC side of other multiphase rectifier	13
17	Saturable reactor devices in 1Ø rectifiers, vapor lamps, welders, frequency changes, power tools, inductions heaters, etc.	10
18	Resonance in balanced or residual circuit of power system. Frequently due to shunt capacitors	6
19	Gas tubes firing. Often related to source 1 above.	14
20	Electronic frequency converters (cyclo converters)	

FIGURE 5

3.2 The analysis procedure entails determining which pattern(s) in the "Correlation Matrix" are best matched by the excessive and marginal harmonic frequency levels plotted in the "Level Graph". Then the probable sources associated with the pattern(s) will indicate the direction for continuation of the investigation.

3.2.1 First study the level graph and identify those harmonic frequencies exceeding the $\mu + \sigma$ limit. Number those with the greatest deviation by letting 1 = highest, 2 = next highest, etc. Post the dB value by which σ is exceeded.

3.2.2 Next fill in the matrix by placing an (X) in each circle associated with each harmonic frequency having a posted value greater than σ. Also place a single diagonal stroke (/) in each circle corresponding to a harmonic frequency with a posted value greater than μ and less than σ.

3.2.3 Now examine each horizontal line of the matrix for near correlations. On the lines identified lightly place an (X) or (/), as appropriate, in any harmonic frequency columns containing excessive or marginal posted levels which do not have a circle in the matrix.

3.2.4 Again study each line of the matrix to determine where the closest circle-by-circle match occurs. This is rarely a clear cut decision. When there are several near matches the one with the closest match must be identified.

3.2.4.1 Let each X=1 and each /=0.5. Each X or / in a circle is a match and each X or / that is not in a circle is a miss. Add the matches and misses along each horizontal line of the matrix where there is a near match. A circle which does not contain an X or / is counted a miss.

3.2.4.2 Calculate the correlation percentage by dividing the number of matches by the sum of the matches and misses. Enter the percentage at the end of the appropriate line in the matrix. Number the correlation percentages in sequence from the highest to the lowest. When there is a single predominant frequency Line 18 is number 1 regardless of other correlations. The most probable source of the noise problem is number 2, etc.

3.2.4.3 Assume, for example, a line in the matrix has ⊗ ○ / X ⊗ ⊘ (1 match, 1 miss, 0.5 miss, 1 miss, 1 match, 0.5 match). There are 2.5 matches and 2.5 misses. The correlation percentage is 2.5 divided by 5 equals 0.5 (50%).

3.2.4.4 This method for determining the nearest match is a guide to help identify a probable source. It must be tempered by judgement based on experience and additional considerations such as the notes in Part V of the matrix.

3.2.5 There will frequently be more than one power system source existing during a noise investigation. When a single probable source can be identified with the correlation percentage it is advisable to mitigate it first. Then make a second measurement of the harmonic frequencies. Plotting the results of the second measurement to the matrix will permit easier identification of the second source.

3.3 Conditions within a power system that produce distinctive harmonic frequency patterns in the telephone system power influence are generally related to capacitor, transformer and rectifier installations. There are other sources that are infrequently encountered during noise investigations. Some typical relationships are discussed below to aid in the decision process during noise investigations.

3.3.1 Shunt capacitors installed along power systems (See TE&CM Section 451, Paragraph 7.52), while not a source of harmonic frequencies, can contribute significantly to the severity of telephone system noise. Circuit resonance which is frequently aggravated by the presence of capacitor banks is indicated when the zero-sequence (odd-triple) third, ninth and fifteenth are in the marginal or excessive range as shown in line 4 of the matrix. Harmonic frequencies above the fifteenth harmonic seldom occur as a result of resonance. The ninth harmonic (540 Hz) will frequently be the predominant harmonic (6 dB or above the next worst harmonic. When this occurs the single outstanding harmonic condition of line 18 will be applicable.

3.3.1.1 A malfunctioning capacitor bank will produce a harmonic pattern similar to that illustrated in line 3 of the matrix. The fifth, seventh and eleventh harmonics will be in the marginal or excessive range. The fifth harmonics (300 Hz) may appear as a single predominant harmonic. Also the ninth harmonic may appear, with the three commonly found, as a predominant harmonic (See paragraph 3.3.1). A malfunctioning capacitor bank can occur when a capacitor accidently is left connected to a phase conductor during the removal of a three-phase capacitor bank. It may also occur if a fuse is blown removing one capacitor of a three-phase bank. The condition might also occur where a capacitor bank is switched in and out by a time clock. If one of the switch blades does not make good contact one of the capacitors may not be connected to the phase wire.

3.3.1.2 Some transformer related problems can be aggravated by capacitor bank installations. Among these are distribution transformers with a silicom iron core (See paragraph 3.3.2.1).

3.3.2 The transformers installed along power systems can be a source of fundamental frequency harmonics which may interfere with nearby telephone systems. (See TE&CM Section 451, Paragraph 7.51). An overexcited transformer primary winding (Excessive primary voltage level) will produce harmonics. As illustrated in line 6 of the matrix the odd harmonics from the third through the fifteenth (180 through 900 Hz) are likely to exceed (μ). The transformer primary voltage levels are usually set to provide the correct secondary voltage during periods of high power demand. When the demand is low the primary voltage levels may exceed those that result in efficient operation and harmonics are produced. The ninth harmonic (540 Hz) will often be found as the predominant frequency.

3.3.2.1 Excitation currents in power transformers with silicon iron cores may also produce harmonic frequencies. Sometimes these harmonics are aggravated by circuit resonance and capacitor banks. The harmonic frequencies exceeding μ will usually produce a pattern similar to the one shown in line 5 of the matrix. Excessive values will seldom be found above the thirteenth harmonic (780 Hz).

3.3.2.2 A defective step-down power transformer will produce a harmonic frequency pattern similar to that shown in line 7 of the matrix.

3.3.2.3 A harmonic frequency pattern similar to the one illustrated on line 8 of the matrix will likely be due to a grounded three-phase transformer, a grounded-Y auto-transformer or a transformer that is not equipped with or has an inadequate tertiary winding. A tertiary winding is normally used on transformers installed at substations. The terminals of the tertiary winding may or may not be brought out on bushings to permit using the voltage output.

3.3.3 Multiphase rectifiers such as used with high voltage direct current (HVDC) transmission lines produce a different pattern. (See TE&CM Section 451, Paragraph 7.7). Line 12 of the matrix illustrates the harmonic pattern appearing on the ac side of a six-phase rectifier. This same pattern is sometimes associated with an SCR control device (See also paragraph 3.3.4.4).

3.3.3.1 The harmonic pattern appearing on the dc side of a multiphase rectifier is conspicuous because it consists of all even harmonics. The lowest harmonic is equal to the number of phases in the rectifier. The pattern found on the dc side of a six-phase rectifier is illustrated in line 13 of the matrix.

3.3.3.2 When the harmonic source is a twelve-phase rectifier the pattern on the ac side is similar to the one for six-phase rectifier shown on line 12 except the fifth and seventh, the seventeenth and nineteenth, etc., harmonics (300, 420, 1020, 1140 Hz. etc) are no longer present. The pattern appearing on the ac side of a twelve-phase rectifier is shown on line 14.

3.3.3.3 The harmonic pattern appearing on the dc side of a twelve-phase rectifier consists of all even harmonics as was discussed for six-phase rectifiers in paragraph 3.3.3.1. The pattern is shown in line 15 of the matrix.

3.3.3.4 A pair of adjacent nonzero-sequence harmonics above the twenty third (1380 Hz) are usually due to a multi-phase rectifier installation. These patterns which will appear on the ac side of the rectifier are shown in line 16 of the matrix.

3.3.3.5 A string of consecutive odd and even harmonics such as shown in line 17 of the matrix may be due to the presence of saturable reactor devices in a single phase rectifier. There are other devices which can produce the same pattern such as "vapor" lamps, welders, frequency changers, power tools, induction heaters, etc.

3.3.4 There are other distinctive patterns which can indicate a harmonic frequency source from other than an identifiable component of the power system. Such sources might be associated with customer owned devices connected to either the power or telephone system. One pattern often found is illustrated in line 1 of the matrix where the fundamental frequency (60 Hz) component appears as a single outstanding frequency. This is usually the result of a poorly balanced three-phase power system parallel to the telephone plant. It might also be due to a long parallel exposure to a single-phase power circuit. Sometimes it can occur when one or two capacitors of a three-phase capacitor bank are not working.

3.3.4.1 When an open shield exists along the telephone cable a string of odd harmonic frequencies will be found as illustrated in line 2 of the matrix. If the open cable shield is the predominant problem the harmonic frequency levels will be essentially the same difference from the mean levels.

3.3.4.2 Balanced harmonics from a generator, synchronous motor or condensor will usually produce one or two adjacent pairs of odd nonzero-sequence harmonics of those shown in line 9. Where the frequencies are not precise harmonics of 60 Hertz, "slot" harmonics from an induction motor may be indicated.

3.3.4.3 An open lamp on a series street lighting circuit employing individual transformers will produce a string of odd harmonics up to about 3000 Hertz. The resulting harmonic pattern will be similar to the one shown in line 11 of the matrix.

3.3.4.4 Silicon controlled rectifier (SCR) control devices will usually produce a harmonic frequency pattern as shown in line 10 of the matrix. In some cases the pattern may resemble that shown in line 12.

3.3.4.5 When multiple harmonics are found that are not harmonics of the 60 Hertz fundamental frequency they are likely due to the electronic frequency converters (cyclo converters).

4. EXAMPLE

4.1 The example assumes a noise problem exists along a cable route and measurement of the power influence harmonic frequency levels has been completed at a subscriber station protector. The results of these measurements are recorded on a Harmonic Analysis Data Sheet as shown in Figure 6. Also make a sketch of the exposure in the appropriate area (I) of the Cable Pair Harmonic Analysis Matrix (Figure 7).

4.1.1 Enter in the level graph (II) of the Cable Pair Harmonic Analysis Matrix those harmonics with recorded values equal to or exceeding the mean values listed in column 3 of the data sheet as shown in Figure 7. Study the level graph to determine if there are predominant frequencies. Four frequencies are found in Figure 7 that exceed the σ limit by a greater margin than all others. The ninth harmonic (540 Hz.) exceeds σ by 25 dB so mark this

HARMONIC ANALYSIS DATA SHEET

REA TE&CM 452.1

Company Alpha Date 10/15/79

Exchange Beta Time 9:00 a.m.

Route A2 PED A2-30 Pair 152

Tested By DOC

Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)
1	60	110	115
2	120		106
3	180	103	97
4	240		92
5	300	92	83
6	360		80
7	420	98	77
8	480		77
9	540	112	77
10	600		70
11	660	70	65
12	720		61
13	780	74	58
14	840		57
15	900	80	55
16	960		51
17	1020	65	48
18	1080		47
19	1140	58	46
20	1200		45
21	1260	51	44
22	1320		43
23	1380	50	43
24	1440		42
25	1500	33	42
26	1560		41
27	1620	44	41
28	1680		41
29	1740	45	41
30	1800		40
31	1860	31	39
32	1920		39
33	1980		38
34	2040		38
35	2100		37
36	2160		37
37	2220		37
38	2280		36
39	2380		35
40	2400		35
41	2460		34
42	2520		34
43	2580		34
44	2640		34
45	2700		34
46	2760		34
47	2820		34

Overall Noise Measurement

3kHz.

Power Influence (Ng+40)	115.0	dBrn
Circuit Noise (Nm)	44.0	dBrn
Balance	71.0	dB

C-Msg.

Power Influence (Ng+40)	105.5	dBrnc
Circuit Noise (Nm)	28.0	dBrnc
Balance	77.5	dB

FIGURE 6

EXAMPLE-DATA SHEET-FIRST MEASUREMENT

Company Alpha Date 10/15/79

Exchange Beta Time 9:00 a.m.

Route A2 PED A2-30 Pair 152

Tested by DOC

CABLE PAIR TROUBLE ANALYSIS MATRIX
(For problems not related to circuit balance, shield continuity or grounding)

LEGEND
- Open (-)
- + & -
- First Test
- Second Test
- Third Test

I. SKETCH OF TERRAIN AND NEARBY FACILITIES

Show: Mileage of both to nearest 1/10 mile: Type telephone facility, e.g. aerial & buried cable, open wire, etc.; Type power exposure, number of phases, Delta, Y-MGN, etc., capacitor bank locations, etc.

Substation 7.6kV, Y-MGN 3Ø 1Ø 1Ø

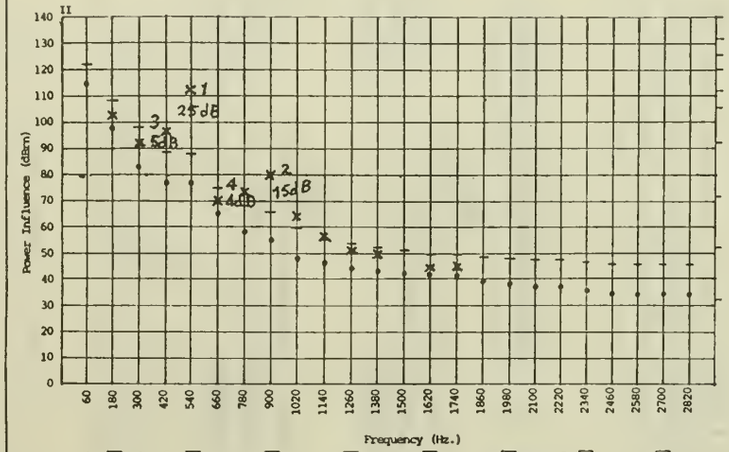
Separation 60' 30' 60'

CO

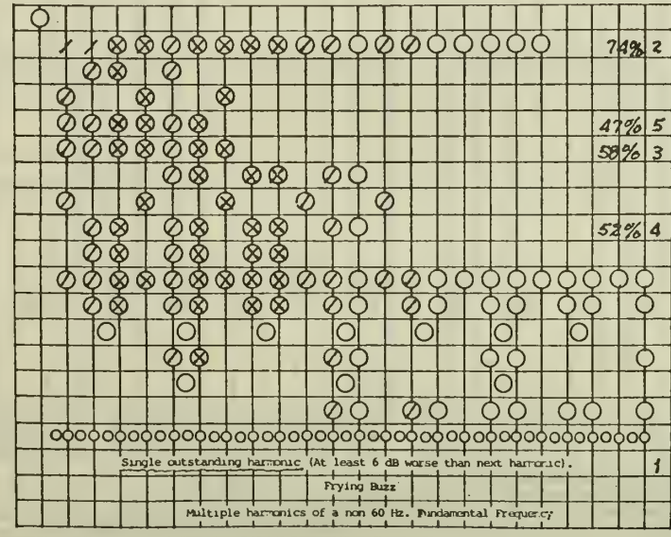
Test Point Ped A2-30

X = L.P

II



III


74% 2
47% 5
58% 3
52% 4
Single outstanding harmonic (At least 6 dB worse than next harmonic). 1
Frying Buzz
Multiple harmonics of a non 60 Hz. Fundamental Frequency

V

1. Sometimes accompanied by carbon block dusting or shorting. May also produce gas tube firing.
2. For long single exposures, a 1:1 power transformer may provide a solution.
3. Sometimes caused by open fuses protecting capacitors connected to one or two phase wires.
4. Each higher harmonic deviating more from the mean (assumes that all harmonics are at the same level). This is not always the case.
5. The 420 or 660 Hz. harmonic frequency may not appear predominately.
6. Usually occurs below the 15th harmonic. Can often be improved by relocating capacitors nearer to substation, installation of resistant shunt in capacitor bank ground wire or using a nongrounded (floating) capacitor configuration.
7. Seldom produces harmonics above the 13th.
8. Usually occurs during periods of low power demand.
9. Ninth harmonic (540 Hz) will often be predominant.
10. A high third harmonic may be due to ballast operated gaseous-discharge lamps (flourescent, mercury vapor, etc.).
11. Usually one (or two adjacent) sets of odd, nontriple harmonics.
12. Frequencies may not be exact harmonics of 60 Hz. which may be due to "slot" harmonics from induction motors. If a ripple (120 Hz. - from the resonance of two adjacent slot frequencies) is present, it may be caused by slot effects of "rotating field" generators.
13. One adjacent pair of nontriple harmonics is sufficient to suggest rectifier problems.
14. Usually occurs during periods of peak power demand.

IV	PROBABLE SOURCE	(V) SEE NOTES
1	Poorly balanced 3Ø power line, long exposure to single or 2Ø power circuits, or one or two capacitors of a 3Ø capacitor bank not functioning	1, 2, 3
(2)	Open cable shield	4
3	Malfunctioning capacitor bank(s)	5
4	Circuit resonance. Usually aggravated by capacitor bank(s)	6, 10
(5)	Exciting currents of silicon iron core distribution transformers. Can be aggravated by circuit resonance due to shunt capacitors	7
(6)	Overexcited power transformers	8, 9
7	Defective power step-down transformer	
8	Grounded 3Ø transformer, transformer either with an inadequate or without a tertiary winding, or a grounded-Y autotransformer	10
(9)	Balanced harmonics from generator, synchronous motor or condenser	11, 12
10	SCR control devices	
11	Open lamp on series street lighting circuit using individual transformers	
12	AC side of 6Ø rectifier or SCR control devices	13
13	DC side of 6Ø rectifier	
14	AC side of 6Ø rectifier	13
15	DC side of 12Ø rectifier	
16	AC side of other multiphase rectifier	13
17	Saturable reactor devices in 1Ø rectifiers, vapor lamps, welders, frequency changers, power tools, inductions heaters, etc.	10
(18)	Resonance in balanced or residual circuit of power system. Frequently due to shunt capacitors	6
19	Gas tubes firing. Often related to source 1 above.	14
20	Electronic frequency converters (cyclo converters)	

FIGURE 7

EXAMPLE-MATRIX-FIRST MEASUREMENT

#1 as shown. The fifteenth (900 Hz), seventh (420 Hz) and thirteenth (780 Hz) harmonics exceed σ by 15, 5 and 4 dB so mark them 2, 3 and 4 respectively. Since the 500 Hertz component exceeds the next highest harmonic level by more than 6 dB it is a single outstanding harmonic frequency. Place the number 1 next to the line number 18 and place a circle around the 18 indicating this is the best match.

4.1.2 Next fill in the correlation matrix III by placing an (X) or (/) in each circle below a harmonic frequency with a plotted value in the level graph higher than the indicated μ. (See paragraph 3.2.2) Study the matrix. In the example there appear to be possible correlations with lines 2, 5, 6, and 9. It might appear that there are other likely correlations but these can be ruled out by considering the number of plotted values which have no circles in the matrix. Place an (X) or (/) under each harmonic frequency with a plotted value in the level graph higher than μ on lines 2, 5, 6, and 9 where there is no circle.

4.1.3 Calculate the correlation percentages as discussed in paragraphs 3.2.4.1 and 3.2.4.2. In line 2 there are 8.5 hits and 3 misses. 8.5 divided by 11.5 equals 0.739 or 74 percent. Line 5 has 4.5 hits and 5 misses. 4.5 divided by 9.5 equals 0.474 or 47 percent. There are 5.5 hits on line 6 and 4 misses. 5.5 divided by 9.5 equals 0.579 or 58 percent. In line 9 there are 5.5 hits and 5 misses. 5.5 divided by 10.5 equals 0.524 or 52 percent. Enter the correlation percentages at the right hand end of the appropriate line in the matrix next to the line number. Based on the correlation percentages line 2 is numbered 2, line 6 numbered 3, line 9 numbered 4 and line 5 numbered 5. The line numbers 2, 5, 6 and 9 are circled.

4.2 Since the 540 Hertz component (9th harmonic) is predominant and there is a capacitor bank installed along the three phase power system as shown in the sketch this should be investigated first. This course of action is supported by the correlation of line six since in the event of overexcited transformers the 540 Hertz component is often presominat. While it appears there may be an open shield this might not be a valid indication in the presence of the single dominant frequency.

4.2.1 Investigation of the effects of a capacitor bank on the power system can be accomplished by monitoring the magnetic field intensity of the predominant harmonic frequency with an exploring coil along the power line. This will usually verify that if the harmonic frequency current appears to be flowing to ground at the capacitor bank. Then the magnitude of the earth return current can be measured with an exploring coil at various locations along the power line. The recorded results of these measurements provide information which will be meaningful to power company engineers during inductive coordination meetings. These techniques for studying the power system are discussed in detail in TE&CM Section 452.2.

4.2.2 For the purposes of this example it will be assumed an apparent resonance is found in the power system with a low impedance to ground through the capacitor bank ground connection. The measured earth return current of the power system between the capacitor bank location and the power substation is 0.8 amperes. This establishes adequate evidence of a power system problem justifying a dialogue with the power company.

4.3 Contact the power company and present to them the data obtained relative to the earth return current. When they concur with the principal of a possible power system related problem arrange for the temporary removal of the ground connection to the capacitor bank. During the period the ground connection is removed remeasure the power influence harmonic frequency levels at the same subscriber station protector as in paragraph 4.1. The recorded results of these measurements for the example are recorded on a Harmonic Analysis Data Sheet as shown in Figure 8.

4.3.1 Enter in the level graph (II) of the Cable Pair Harmonic Analysis Matrix those harmonics from the remeasurement with recorded values equal to or exceeding the mean values listed in column 3 of the data sheet as shown in Figure 9. Study the level graph to determine if there are any predominant frequencies and compare it to the level graph from the initial measurements to determine if changes are evident. There is no longer a single predominant frequency. The eleventh (660 Hz) and fifteenth (900 Hz) harmonics exceed σ by 5 dB and the ninth (540 Hz) by 4 dB. This is a definite improvement over the initial results and proves the capacitor bank was contributing to the overall telephone system noise problem.

4.3.2 Next fill in the correlation matrix as shown in paragraph 4.1.2. Study the matrix. There appears to be possible correlations with lines 2, 5, and 6. These three lines also appeared as potential correlations during the analysis of the initial measurements.

4.3.2 Calculate the correlation percentages as was done for the initial measurements (See paragraph 4.1.3). In line 2 there are 6.5 hits and 5.5 misses. 6.5 divided by 12 equals 0.542 or 54 percent. Line 5 has 5 hits and 3 misses. 5 divided by 8 equals 0.625 or 63 percent. There are 6 hits and 2 misses on line 6. 6 divided by 8 equals 0.75 or 75 percent. Enter the correlation percentages at the right hand end of the appropriate line in the matrix next to the line number. Based on the calculated correlation percentages on lines 6, 5, and 2 enter number 1, 2 and 3 respectively and circle the line numbers.

4.4 It is evident that the removal of the capacitor bank ground connection has reduced the power influence in the telephone system. This can be further verified by measurement of the 540 Hertz earth return current along the power line. For the purposes of the example it is assumed that recorded results of the earth current measurements show there is now only 0.02 amperes flowing between the capacitor bank location and the power substation.

4.4.1 There has been a significant reduction in the correlation percentage associated with line 2 (open cable shield). The possibility of an open cable shield need no longer be considered. A significant increase in correlation percentage appears in lines 5 and 6 which relate to transformer excitation. The presence of overexcited power transformers cannot be proven without the assistance of power company personnel.

4.4.2 Contract the power company and discuss with them the data obtained during the period the ground connection to the capacitor bank was removed. While there is conslusive evidence that the capacitor bank is a major contributor to the overall noise problem the decision as to what to do

HARMONIC ANALYSIS DATA SHEET

REA TE&CM 452.1

Company *Alpha* Date *10/16/79*

Exchange *Beta* Time *11:00 a.m.*

Route *A2* *PED A2-30* Pair *152*

Tested By *DOC*

Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)	Harmonic	1. Freq. Hz	2. PI Level (Ng+40) (dBrn 3KHz)	3. Disregard If Levels Are Less Than (dBrn 3KHz)
1	60	*110*	115	37	2220		37
2	120		106	38	2280		36
3	180	*100*	97	39	2380		35
4	240		92	40	2400		35
5	300	*100*	83	41	2460		34
6	360		80	42	2520		34
7	420	*90*	77	43	2580		34
8	480		77	44	2640		34
9	540	*92*	77	45	2700		34
10	600		70	46	2760		34
11	660	*79*	65	47	2820		34
12	720		61				
13	780	*61*	58				
14	840		57				
15	900	*72*	55				
16	960		51				
17	1020	*52*	48				
18	1080		47				
19	1140	*40*	46				
20	1200		45				
21	1260	*50*	44				
22	1320		43				
23	1380	*40*	43				
24	1440		42				
25	1500	*30*	42				
26	1560		41				
27	1620	*45*	41				
28	1680		41				
29	1740	*45*	41				
30	1800		40				
31	1860	*31*	39				
32	1920		39				
33	1980		38				
34	2040		38				
35	2100		37				
36	2160		37				

Overall Noise Measurement

3kHz.

Power Influence (Ng+40)	*112.5*	dBrn
Circuit Noise (Nm)	*43.5*	dBrn
Balance	*69.0*	dB

C-Msg.

Power Influence (Ng+40)	*89.0*	dBrnc
Circuit Noise (Nm)	*12.5*	dBrnc
Balance	*76.5*	dB

FIGURE 8

EXAMPLE-DATA SHEET-SECOND MEASUREMENT

CABLE PAIR HARMONIC ANALYSIS MATRIX

(For problems not related to circuit balance, shield continuity or grounding)

Company: Alpha Date: 10/16/79

Exchange: Beta Time: 11:00 a.m.

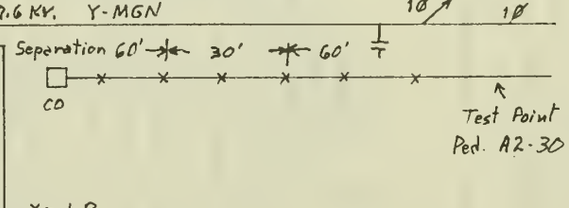
Route: A2 PED A2-30 Pair: 152

Tested by: DOC

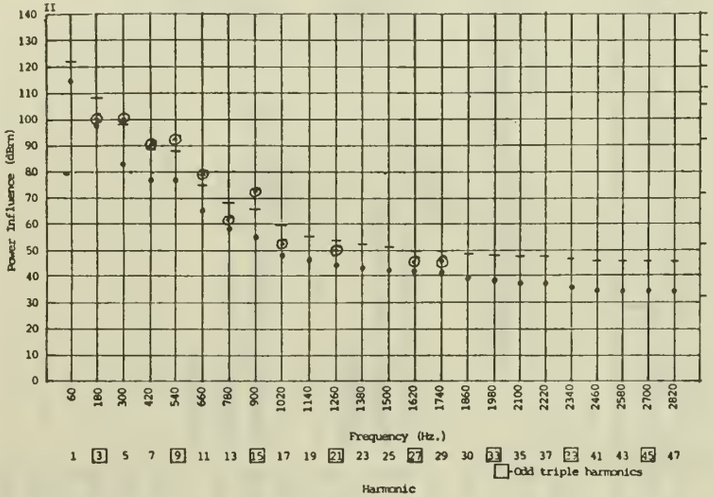
LEGEND
- Mean (-)
- + & -
- First Test
- Second Test
- Third Test

I. SKETCH OF TERRAIN AND POWER FACILITIES

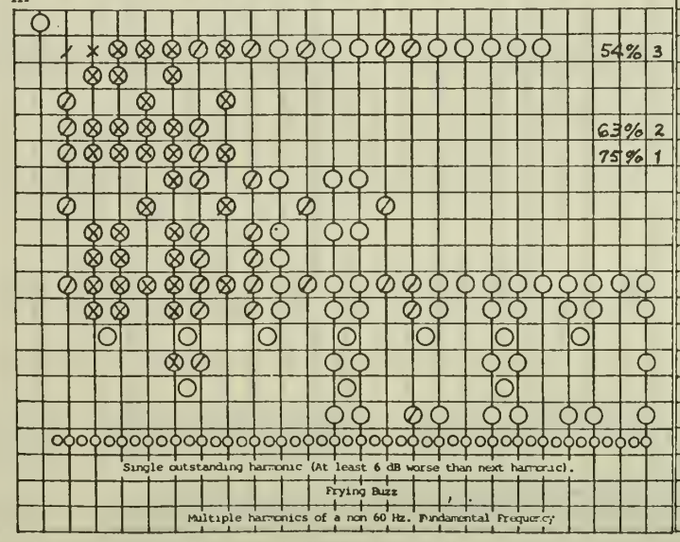
Show: Mileage of both to nearest 1/10 mile; Type telephone facility, e.g. aerial & buried cable, open wire, etc.; Type power exposure, number of phases, Delta, Y-MGN, etc., capacitor bank locations, etc.



II



III


54% 3
63% 2
75% 1
Single outstanding harmonic (At least 6 dB worse than next harmonic).
Frying Buzz
Multiple harmonics of a non 60 Hz. Fundamental Frequency

V

1. Sometimes accompanied by carbon block dusting or shorting. May also produce gas tube firing.
2. For long single exposures, a 1:1 power transformer may provide a solution.
3. Sometimes caused by open fuses protecting capacitors connected to one or two phase wires.
4. Each higher harmonic deviating more from the mean (assumes that all harmonics are at the same level). This is not always the case.
5. The 420 or 660 Hz. harmonic frequency may not appear predominately.
6. Usually occurs below the 15th harmonic. Can often be improved by relocating capacitors nearer to substation, installation of resonant shunt in capacitor bank ground wire or using a nongrounded (floating) capacitor configuration.
7. Seldom produces harmonics above the 13th.
8. Usually occurs during periods of low power demand.
9. Ninth harmonic (540 Hz) will often be predominant.
10. A high third harmonic may be due to ballast operated gaseous-discharge lamps (flourescent, mercury varpor, etc.).
11. Usually one (or two adjacent) sets of odd, nontriple harmonics.
12. Frequencies may not be exact harmonics of 60 Hz. which may be due to "slot" harmonics from induction motors. If a ripple (120 Hz. - from the resonance of two adjacent slot frequencies) is present, it may be caused by slot effects of "rotating field" generators.
13. One adjacent pair of nontriple harmonics is sufficient to suggest rectifier problems.
14. Usually occurs during periods of peak power demand.

IV

	PROBABLE SOURCE	(V) SEE NOTES
1	Poorly balanced 3Ø power line, long exposure to single or 2Ø power circuits, or one or two capacitors of a 3Ø capacitor bank not functioning	1, 2, 3
2	Open cable shield	4
3	Malfunctioning capacitor bank(s)	5
4	Circuit resonance. Usually aggravated by capacitor bank(s)	6, 10
5	Exciting currents of silicon iron core distribution transformers. Can be aggravated by circuit resonance due to shunt capacitors	7
6	Overexcited power transformers	8, 9
7	Defective power step-down transformer	
8	Grounded 3Ø transformer, transformer either with an inadequate or without a tertiary winding, or a grounded-Y autotransformer	10
9	Balanced harmonics from generator, synchronous motor or condenser	11, 12
10	SCR control devices	
11	Open lamp on series street lighting circuit using individual transformers	
12	AC side of 6Ø rectifier or SCR control devices	13
13	DC side of 6Ø rectifier	
14	AC side of 6Ø rectifier	13
15	DC side of 12Ø rectifier	
16	AC side of other multiphase rectifier	13
17	Saturable reactor devices in 1Ø rectifiers, vapor lamps, welders, frequency changers, power tools, inductions heaters, etc.	10
18	Resonance in balanced or residual circuit of power system. Frequently due to shunt capacitors	6
19	Gas tubes firing. Often related to source 1 above.	14
20	Electronic frequency converters (cyclo converters)	

FIGURE 9

EXAMPLE-MATRIX-SECOND MEASUREMENT

about the bank should be left to the power company. There are two courses of action they might take, relocate the capacitor bank closer to the power substation or install a harmonic shunt in the ground lead to the bank. Power company personnel may wish to make measurements along the power line to confirm there is excess voltage in the transformer primary windings.

4.4.3 There might be some question as to why the possible problem of overexcited transformers should be explored. The overall C-message weighted noise measurements on the data sheet (Figure 8) shown circuit noise level of 12.5 dBrnc which is within the objective limits. This is only possible because of the excellent balance of this cable circuit. It is likely that other pairs in the cable will not have balance this high. A cable pair with an acceptable balance of 60 dB would have a circuit noise of 29 dBrnc. Since the power influence is 89.0 dBrnc which is in the high marginal range it is wise to try and reduce it to 80 dBrnc or lower, if possible.

4.4.4 For the purpose of the example it is assumed that the power company relocated the capacitor bank closer to the substation and reduced the primary voltage of the power line at the substation. Make a final measurement of the C-message weighted noise at the same location as the previous two measurements to determine the effects of the power company work. These recorded results show power influence -81 dBrnc and circuit noise -9 dBrnc for a balance of 72 dB. This is not a true reduction in balance. The induced circuit has been reduced below the threshhold of the steady state noise of the central office at the point of measurement. This noise investigation can now be closed.

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452.2

EXPLORING COIL MEASUREMENTS

Contents

DEPOSITORY
DEC 3 1980
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

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1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for using an exploring coil during noise investigations. Noise investigations may be undertaken where telephone plant is operational, non operational or along proposed routes.

1.2 An exploring coil can be used to locate and identify various power line components that may be contributing to a telephone system noise problem. An exploring coil is also used to measure the overall or

or individual harmonic frequency earth return current of a power line. (See TE&CM Section 452, Paragraph 9.2.)

1.3 An exploring coil is small and lightweight and thus easy to transport. Little time is required at a site to prepare for measurement making it more convenient than a probe wire. (See TE&CM Section 452.3).

1.4 Earth return current is usually measured along a power line after it has been determined that circuit noise in a telephone system cannot be reduced to an acceptable level through further work on the telephone plant. In other words, cable balance is excellent, cable shield continuity has been verified by measurement and the source of the noise is through induction and not within the telephone system. Another situation where the measurement of power system earth return current might be desirable is where a new cable extension is planned parallel to an existing power line. The expected power influence can be calculated from the average earth return current as determined from measurements of earth return current along the proposed route. Thus if a neutralizing transformer is required it can be included in the transmission design or the proposed routing changed.

1.5 The technique for measuring power line earth return currents is effective on single-, two-, or three phase systems. In general, the technique can be used to measure the earth return current associated with any conductor or group of conductors. This also applies to buried telephone cable.

2. EXPLORING COIL SURVEY OF POWER SYSTEM

2.1 An exploring coil in conjunction with a spectrum analyzer can be used for rapid diagnosis of power line operating conditions which may be contributing to a telephone noise problem. This is especially true when an analysis of the power influence on a telephone cable pair as discussed in TE&CM Section 452.1 has identified the predominant harmonic frequency. This frequency will often be 540 Hertz, the ninth harmonic of the fundamental (60 Hertz) power line frequency. When an analysis of the power influence on a cable pair has not been completed this diagnostic tool can still be utilized. Since the ninth harmonic is the predominant interfering frequency in the majority of noise investigations this harmonic may be used for studying the power line where the actual predominant interfering frequency has not been determined.

2.2 Connect the exploring coil to the input of the spectrum analyzer. Set the spectrum analyzer for bridged measurement and to the harmonic frequency of interest. Where the test set has automatic frequency control (AFC) it should be used to compensate for drift. Hold the coil outside the vehicle window and point it directly at the power wires as shown in Figure 1. The coil should be oriented to obtain maximum reading on the analyzer. Some investigators also monitor the audible noise with earphones when a monitor jack is available on the test set.

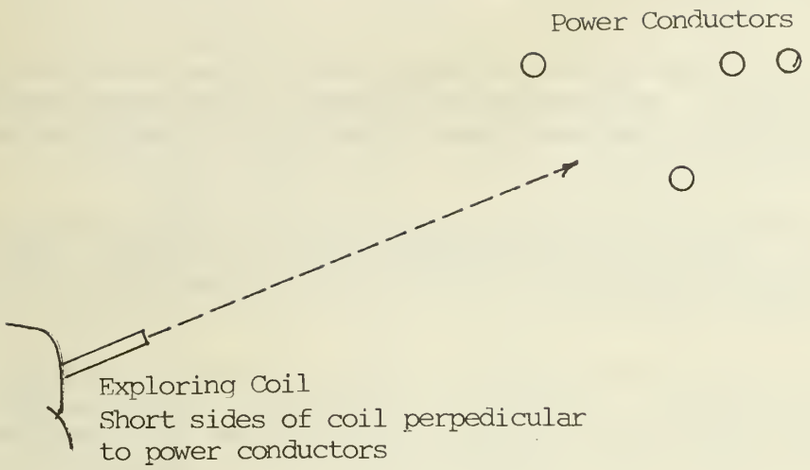


FIGURE 1
POWER SYSTEM SURVEY

2.2.1 Move along the power line in the vehicle observing the magnitude of the harmonic frequency. As the location of the power line changes in relation to the road it will be necessary to reorient the exploring coil to obtain the maximum reading on the analyzer. The entire power line should be studied even though it extends beyond the telephone system. The factor(s) in the power system contributing to telephone interference need not be located in spans where the systems are parallel.

2.2.2 When a point is passed where there is a significant change in the magnitude of the harmonic frequency, return to the point and determine why. Such a change might occur at a capacitor bank location which due to a resonant power line condition is providing a low impedance path to earth for that particular harmonic frequency current. A reduction in magnitude might occur where a tap leaves the main power line and the current is flowing in the tap.

2.2.3 When the reduction occurs at a tap location the tap should be studied in the same manner discussed above until the factor(s) contributing to the noise have been identified. Then the study of the main power line route can be completed.

2.3 After possible contributors to the telephone interference have been identified measurements of the power line earth return current should be completed on both sides of the locations to verify its contribution. The measurement of earth return current with an exploring coil is discussed in Paragraph 3 and with a probe wire in TE&CM Section 452.3.

3. MEASUREMENT OF EARTH RETURN CURRENT

3.1 Selection of a location for measurement of power line earth return currents is an important consideration. It must be free as possible from factors that might produce erroneous results. Things to avoid are:

3.1.1 Power line spans that include secondary distribution conductors should be avoided. The presence of secondary distribution conductors alters the magnetic field and can cause significant errors in earth return current measurements.

3.1.2 Discontinuities in the power line such as bridged taps, distribution transformers, corners or dead-ends should also be avoided. These will distort the magnetic field from the power line and cause errors in the earth return current measurements.

3.1.3 Metal fences located beneath or near a power line and parallel to it should be avoided. The magnetic field from a grounded metal fence may be stronger at the earth's surface than that from the power line. This could result in a large error in earth return current measurements.

3.1.4 Sections where power and telephone lines share poles should also be avoided unless the joint use extends through the entire exposure. Recorded results of measured earth return current where the entire exposure is in joint-use are not the true values. The error is due to the cable's location near the power conductor. Variations in earth return current along the power line and the predominat harmonics of the fundamental frequency can still be determined.

3.1.5 The exploring coil should not be used where a buried cable or metallic pipe line is located beneath or very near the power line. The magnetic field from either of these may be stronger than that from the power line at the earth's surface. This will produce erroneous results.

3.2 The site selected should be at the center of a span to obtain the highest reading on the meter. After a site has been selected for the measurements determine the distance from the center of the exploring coil to the neutral and each phase conductor. Where the distance is estimated the value must be within $\pm$ two (2) feet. The exploring coil is more sensitive to small changes in distance to the powerline than a probe wire (See TE&CM Section 452.3). If available the use of a rangefinder is recommended for determining this distance.

3.2.1 Calculate the average distance to the power conductors from the center of the exploring coil. This will be the average distance to four power conductors (one neutral and three phase conductors) on a three-phase power line. It will be the average of two conductors (one neutral and one phase wire) on a single-phase line.

3.2.2 Enter the average distance in the appropriate space (1) on the form for power system current wave form analysis. A sample form is shown in Figure 2. The sample form is designed for use when measuring with either an exploring coil or probe wire.

POWER SYSTEM CURRENT WAVE FORM ANALYSIS

Central Office _____

Power Company _____ Sheet No. _____

Primary Voltage _____ Date _____

Test Location _____ Time _____

Test Condition _____ Tester _____

☐ 100 foot probe wire _____ ☐ Exploring coil type: _____

Power Line Height (Average) _____ Feet (1); Correction Factor _____ dB (2)

FREQ. Hz.	Harmonic	TIF Weighted (Weighing Switch in C-MSG.)			Unweighted (Weighing Switch in 50 KHZ-FLAT or 20/F)					TIF Contribution	
		Reading dB (3)	(2)+(3) $I_f \cdot W_f$ dBA (4)	$I_f \cdot W_f$ wtd. amps (5)	Flat Reading dB (6)	20/f Factor (7)	(6)+(7)or 20f Reading (8)	(8)+(2) -40 dB =(I_f)dBA (9)	I_f amps (10)	(3)-(8) +40 dB =(T_f) dB (11)	T_f (12)
60	1					-9.5					
120	2					-15.6					
180	3					-19.1					
240	4					-21.6					
300	5					-23.5					
360	6					-25.1					
420	7					-26.4					
480	8					-27.6					
540	9					-28.6					
600	10					-29.5					
660	11					-30.4					
720	12					-31.1					
780	13					-31.8					
840	14					-32.5					
900	15					-33.1					
960	16					-33.6					
1020	17					-34.2					
1140	19					-35.1					
1260	21					-36.0					
1380	23					-36.8					
1500	25					-37.5					
1620	27					-38.2					
1740	29					-38.8					
1860	31					-39.4					
1980	33					-40.0					
2100	35					-40.4					
2220	37					-40.9					
2340	39					-41.4					
2460	41					-41.8					
2580	43					-42.2					
2700	45					-42.6					
2820	47					-43.0					
2940	49					-43.3					
3060	51					-43.7					
3180	53					-44.0					
			(I·T)dB	I·T				(I) dBA	I	(TIF)dB	TIF
PWR SUM											
NMS											

		Height of Power Line Above Probe Wire or Coil								
		20'	25'	30'	35'	40'	45'	50'	55'	60'
Height Correction Factor dB	100' Probe Wire	0.5	1.1	1.6	2.1	2.5	2.9	3.3	3.6	3.9
	Exploring Coil	19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

FIGURE 2

3.2.3 Find the correction factor in the table at the bottom of the form for the average power line height (average distance from center of coil to power conductors) and enter it in the appropriate space (2). The correction factors are based on the dimensions of the Wilcom Products, Inc. CCS-105 exploring coil since, at the time of this writing, it is the only one known to be on the market. This does not constitute an endorsement of this product by REA or imply other exploring coils of equal or other dimensions which might be available cannot be used to measure earth return current. With coils of different area it is necessary to compute new correction factors as discussed in TE&CM Section 452, Paragraph 9.

3.3 Connect the exploring coil to the spectrum analyzer with a two-wire cord having a dual banana plug at each end. Position the exploring coil directly under the power conductors so that the short sides of the coil are perpendicular to the lines and the long sides parallel as shown in Figure 3.

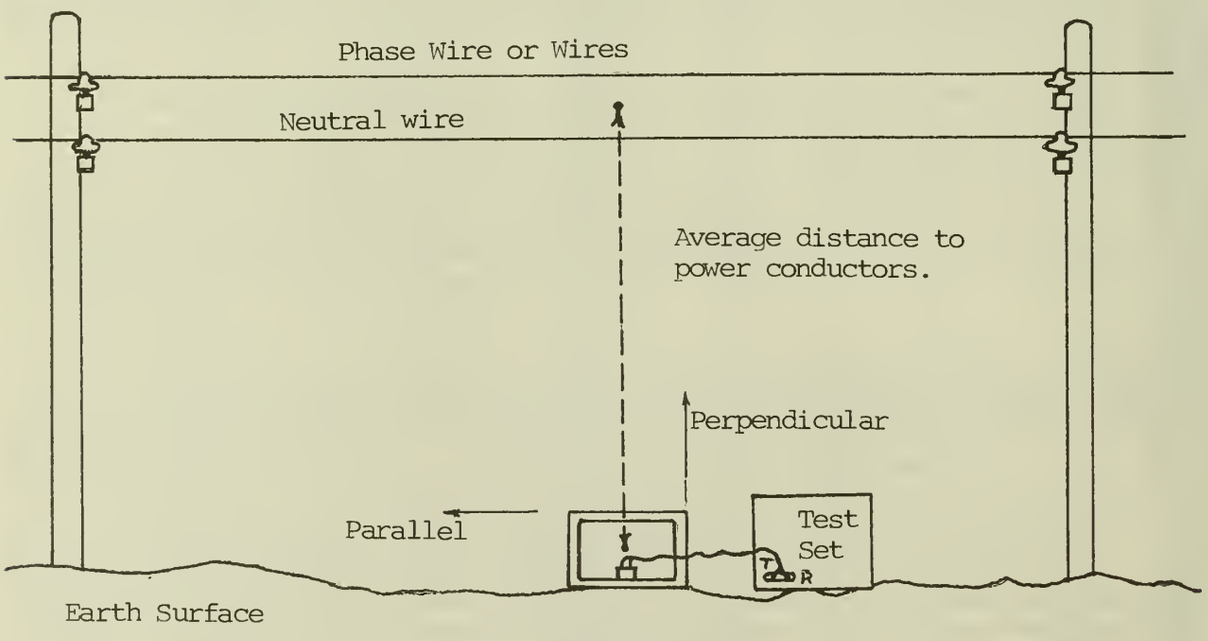


FIGURE 3
MEASUREMENT OF EARTH RETURN CURRENT

3.3.1 When using a spectrum analyzer designed for telephone system measurements set the function switch to the BRDG 600 positon. Place the weighting switch to the desired weighting (C-MSG, 50 kHz FLAT or 20/f), if available.

3.3.1.1 A 50 kHz FLAT weighting filter may not be available on all test equipment. A 3 kHz FLAT weighting should not be used for these measurements since it may be necessary to measure frequencies higher than

the filter cut off frequency. Any higher weighting provided such as 8 kHz FLAT or 15 kHz Flat would be adequate.

3.3.1.2 Not all available test equipment has a 20/f weighted filter. Further, accurate readings with this weighting can only be made at harmonics of the fundamental frequency with a measured valued one tenth ampere or higher earth return current. For example, a reading of 0 dBrn at a point with an average power line height of 20 feet indicates an earth return current of 0.09 ampere. Where long exposures are involved, it is desirable to identify earth return currents of 0.05 ampere. This is a meter reading of -5.5 dBrn. Since with most spectrum analyzers accurate readings cannot be made below 0 dBrn weighting factors in dBrn for 20/f have been included in column (7) of the sample form shown in Figure 2. 20/f weighted values are derived by adding these values to the recorded flat readings. The factors are also used when the available test equipment does not have a 20/f weighted filter.

3.3.2 Set the spectrum analyzer to the desired frequency. Rock the exploring coil slowly from side to side on the longitudinal axis as shown in Figure 4 to the position providing the maximum reading. When the exploring coil and the power line are in the same plane maximum readings of the power line earth return current should be obtained. When the coil at maximum reading is at an angle to the power line plane there is a likelihood it is being influenced by the magnetic field from a buried cable or metallic pipeline.

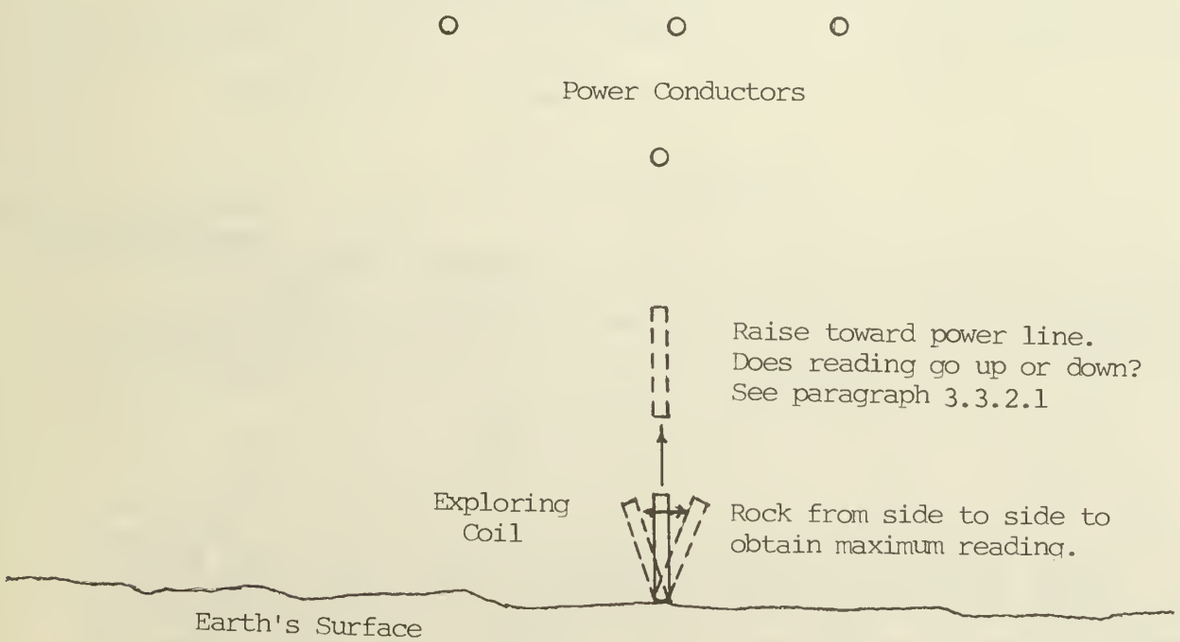


FIGURE 4
PREPARING TO MEASURE EARTH RETURN CURRENT

3.3.2.1 Regardless of previous results lift the coil slowly in the plane of the maximum reading. An increase in the reading indicates the coil is being primarily influenced by the magnetic field from the power line and the measurements may be completed. A decrease in the reading shows the coil is being influenced by the field from a buried cable or metallic pipeline located beneath the power.

3.3.2.2 When a decrease in the reading is found, move the coil thirty feet or more from the power line as shown in Figure 5. Repeat the procedures outlined in Paragraph 3.3.2 and 3.3.2.1 to insure that the coil is being influenced by the magnetic field from the power line. If other influences still mask the power line effects, a new location along the line should be selected for the measurement.

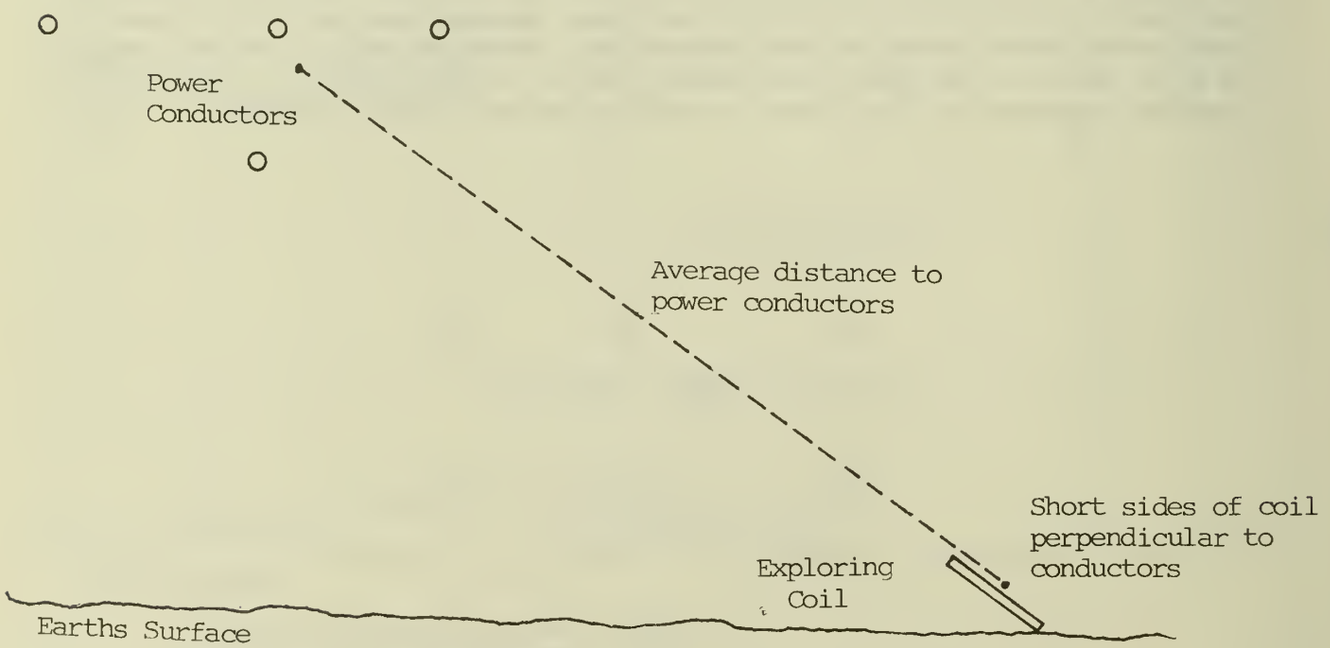


FIGURE 5
ANGULAR MEASUREMENT OF EARTH RETURN CURRENT

3.3.3 After a location free other influences has been found, read and record the values in dBrn on the analysis form for the weightings and frequencies shown. When using the test equipment that does not have 20/f weighting the values will have to be calculated from recorded values of flat weighted readings as shown on the form (See Paragraph 4).

3.3.3.1 Switch the operating mode from spectrum analysis to NMS (noise measuring set). Make an overall reading with C-MSG and 20/f weighting. Record the results in the appropriate spaces of the form along the line designated NMS. These overall readings may be converted to numerical overall values of Telephone Interference Factor (TIF), weighted amperes (I·T), and amperes (I) respectively (See TE&CM Section 452) because they are independent of frequency.

3.3.3.2 An overall flat weighted measurement does not have to be made. Flat weighted measurements are frequency dependent and can only be converted to earth return current (I) on a single frequency basis. An overall flat measurement can be used to check the accuracy of the single frequency measurements. This will be discussed in Paragraph 4.

3.3.4 This completes the measurements at a location. Move to the next location that has been selected and repeat the procedures until measurements have been completed at all desired sites.

4. CALCULATION OF EARTH RETURN CURRENT

4.1 There are two methods for converting the recorded results of measurements to numerical values of TIF weighted amperes (I·T) and amperes (I). One is to calculate them as shown on the form for power system current wave form analysis (Figure 2). The other is to determine the values with nomographs designed for the weighting used, C-MSG, FLAT or 20/f.

4.2 The first step is to convert C-MSG weighted readings in column (3) to TIF weighted dB by adding the correction factor at (2) to the reading and enter it in the $I_f \cdot W_f$dBA column (4) of the form (Figure 2). Complete this operation for each frequency and for the overall NMS reading.

4.2.1 Calculate TIF weighted amperes (I·T) by the equation:

$$I \cdot T = \log^{-1}\left(\frac{I_f \cdot W_f \text{dBA}}{20}\right)$$

4.2.2 TIF weighted amperes may also be determined from the curve shown in Figure 6. Enter the bottom horizontal scale at the calculated $I_f \cdot W_f$dBA value from column (4) of the analysis form. Follow the vertical line to the point it intersects the curve. Read the TIF weighted amperes (I·T) of that point on the left vertical scale. Enter value in column (5).

4.2.3 C-MSG weighted readings may also be converted to TIF weighted amperes by use of the nomograph shown in Figure 7. Enter the nomograph in the left vertical scale at the point of the average distance between the center of the exploring coil and the power conductors. Lay a straight edge from this point through the point on the center vertical scale of the C-MSG weighted reading in dBrn. Read the TIF weighted amperes at the point the straight edge intersects the right vertical scale. Enter this value in column (5).

4.2.3.1 There will be combinations of distance and readings where the straight edge will project beyond the limits of the right vertical scale. Where the scale indicates a value over 100 subtract 20 dB from the

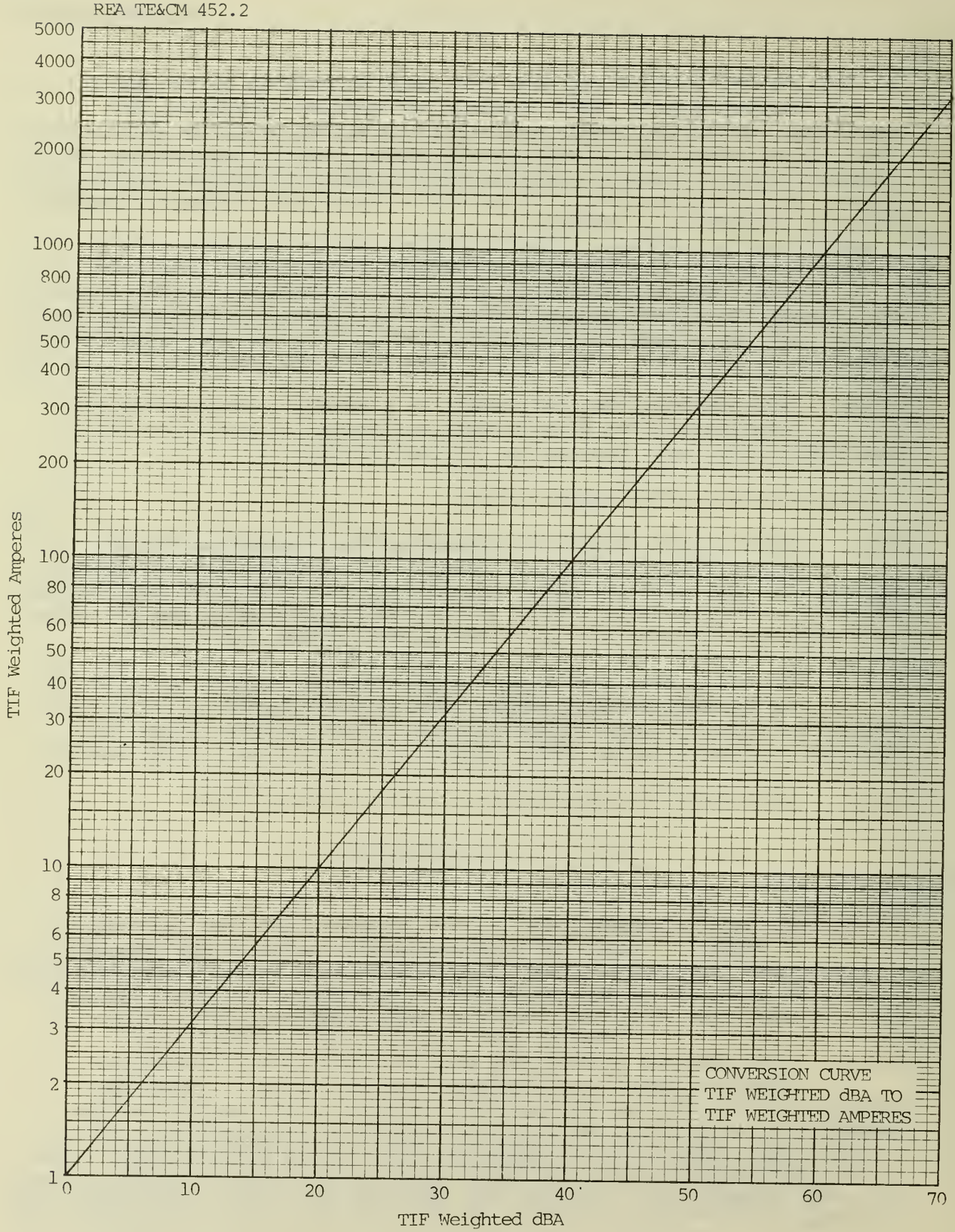
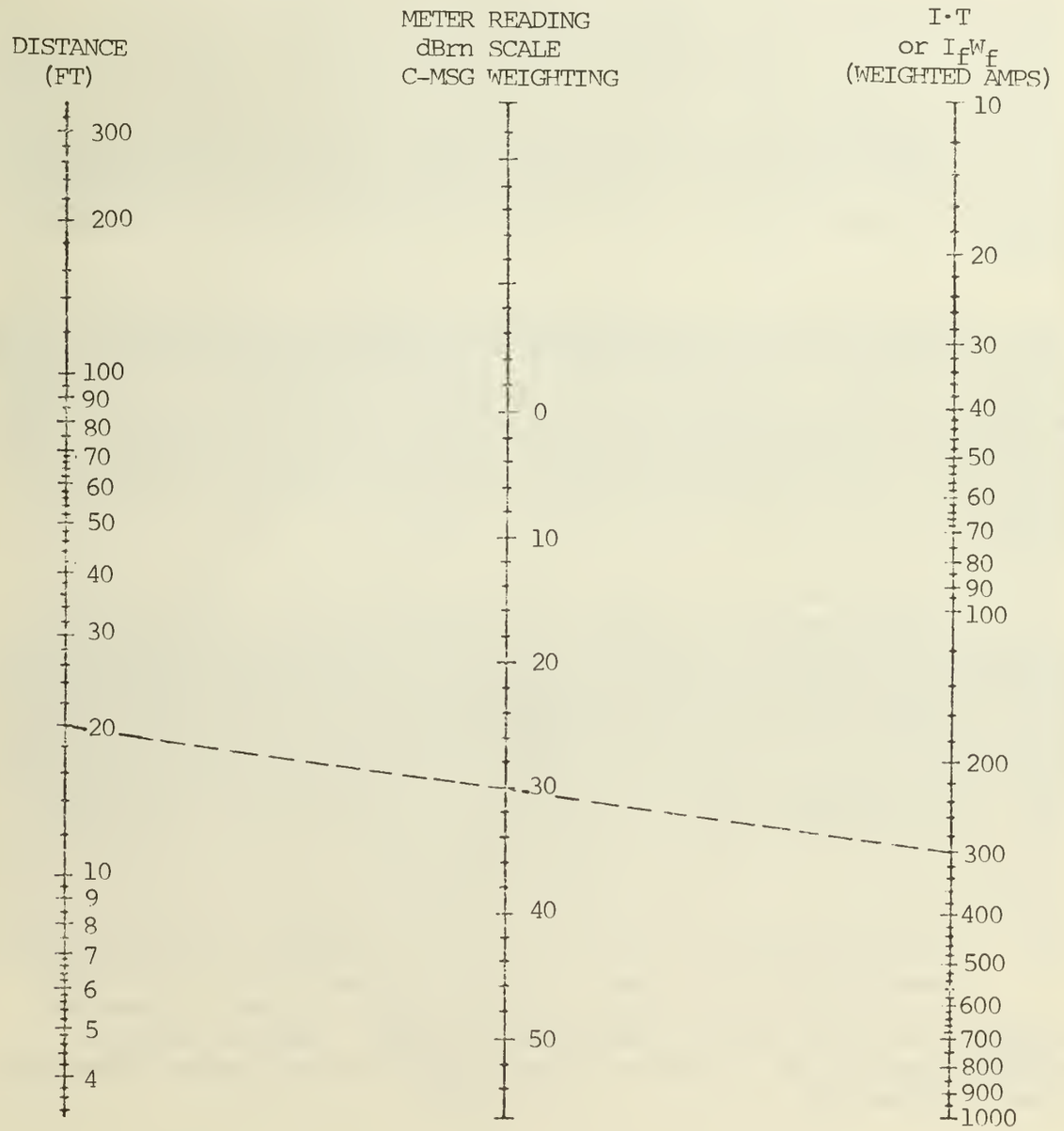

5000
4000
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
TIF Weighted Amperes
0
10
20
30
40
50
60
70
TIF Weighted dBA
CONVERSION CURVE
TIF WEIGHTED dBA TO
TIF WEIGHTED AMPERES

FIGURE 6

reading and realign the straight edge. Multiply the I·T value determined in this manner by 10 to obtain the true I·T. As an example, assume a distance of 20 feet and a reading of 50 dBrn. This will be beyond the limits of the right scale. By subtracting 20 dB the straight edge is laid between 20 and 30 giving a reading of 300 on the right scale. Multiplying this by 10 gives 3000 which is the desired I·T.

4.2.3.2 When the value desired is less than 10, add 20 dB to the reading and realign the straight edge. Divide the reading thus obtained by 10 to obtain the desired I·T.



Courtesy of Wilcom Products, Inc. FIGURE 7

NOMOGRAPH FOR DETERMINING TIF WEIGHTED AMPERES

4.2.4 The operation can be checked by calculating the power summation of columns (3) and (4) and the root sum square (RSS) of column (5). These are both methods for finding the root sum square which is the square root of the sum of the squares of the individual values. Results of power summations are in decibels and of root sum squares in units.

4.2.4.1 The equation for power summation is:

$$\text{PWR SUM} = 10 \log \left(\Sigma \log^{-1} \left(\frac{\text{dB}}{10} \right) \right)$$

4.2.4.2 The equation for root sum square is:

$$\text{RSS} = \sqrt{\Sigma I^2}$$

4.2.5 Calculated values should be nearly equal to the overall measured values in the noise measuring set mode. A large discrepancy indicates an error in either the calculations or in the individual single frequency measurements. This should be found and corrected before proceeding further.

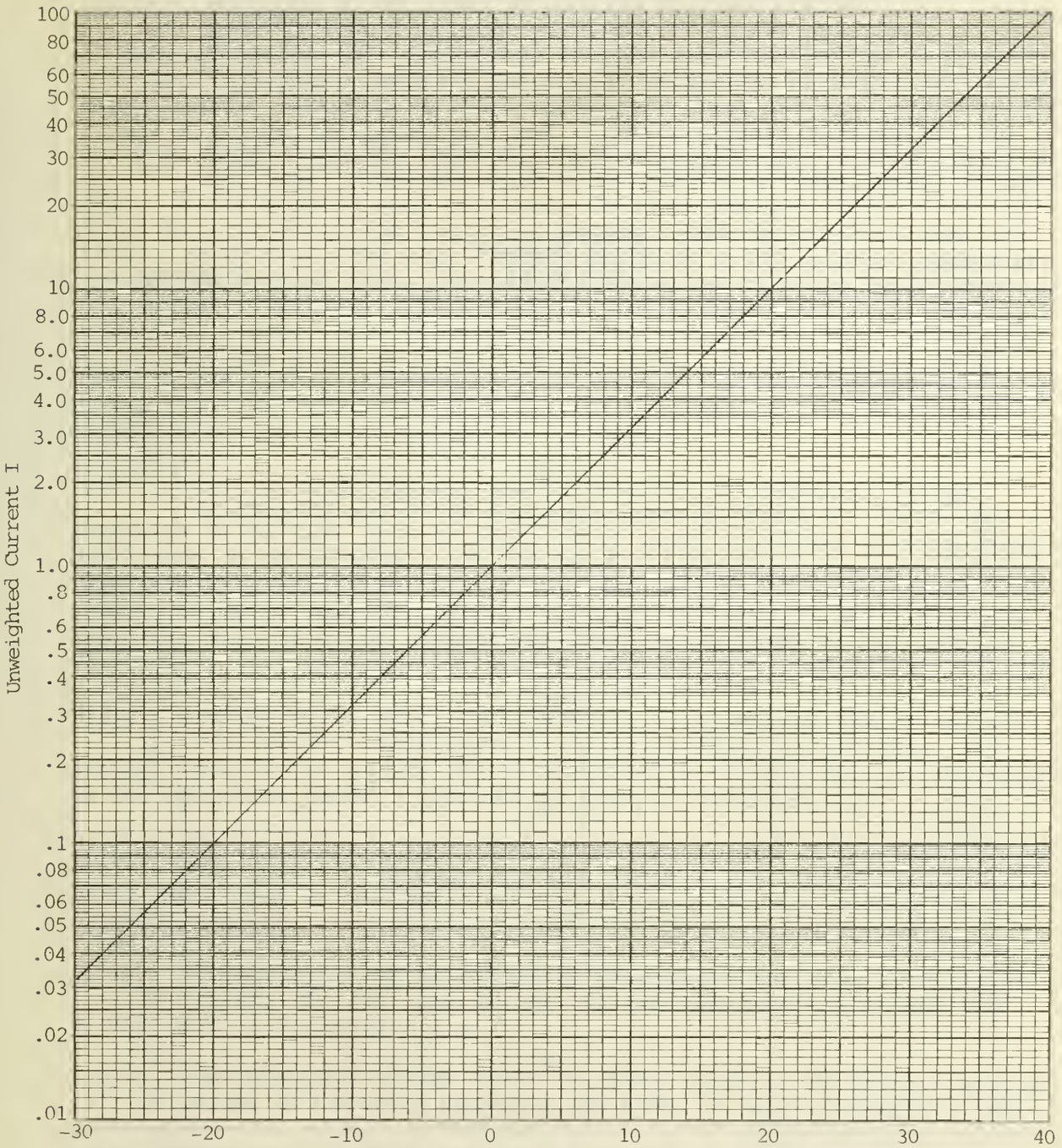
4.3 The next step is to determine the magnitude of the unweighted earth return current. If measurements were made with equipment not having a 20/f filter only the recorded results of flat weighted measurements are available. Convert the results of the flat weighted readings to 20/f values by adding the 20/f weighting factors from column (7) of the analysis form to the recorded flat readings in column (6). Enter the resulting values in column (8). If flat weighted overall readings were taken they cannot be converted to 20/f values since there is no single 20/f factor that can be applied.

4.3.1 When recorded 20/f weighted values are available, either calculated or measured, calculate the unweighted earth return current in (I_f) dBA. Add the correction factor (2) from the analysis form to the recorded 20/f weighted value from the column (8) and subtract 40 from the result. Enter this value of the unweighted current in dBA in column (9). Complete this operation for each frequency and for the overall NMS readings.

4.3.2 The unweighted earth return current in amperes can be calculated from the equation:

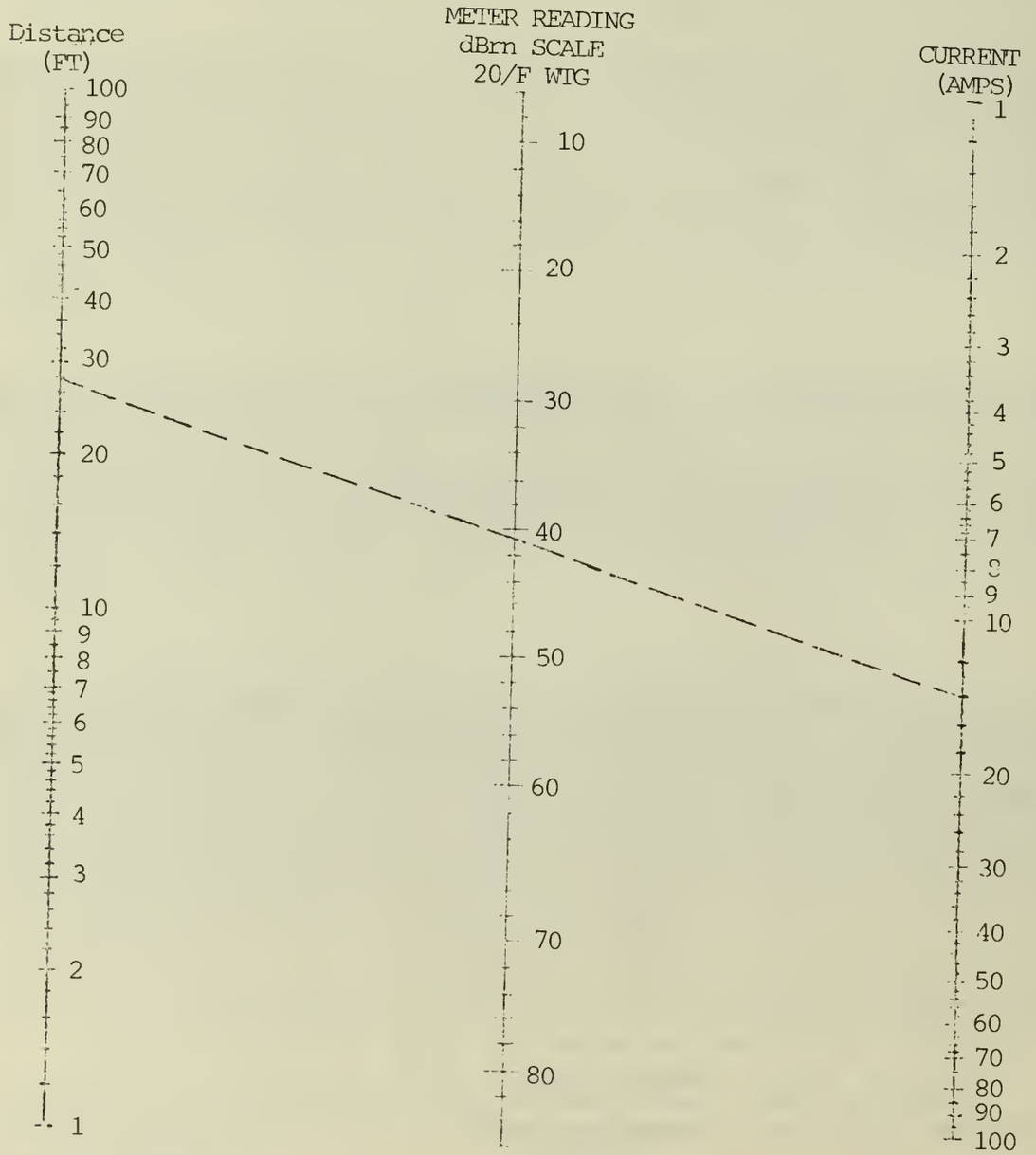
$$I = \log^{-1} \left(\frac{(I_f)\ \text{dBA}}{20} \right)$$

4.3.3 The unweighted ampere value may also be determined from the curve shown in Figure 8. Enter the bottom horizontal scale at the calculated (I_f) dBA value from column (9) of the analysis form. Follow the vertical line to the point it intersects the curve. Read the value of unweighted amperes (I) of that point on the left vertical scale. Enter this value in column (10).



CONVERSION CURVE
dBA to I
FIGURE 8

4.3.4 20/f weighted readings can also be converted to unweighted amperes directly by use of the nomograph shown in Figure 9. Enter the nomograph in the left vertical scale at the point of the average distance between the center of the exploring coil and the power conductors. Lay a straight edge from this point through the point on the center vertical scale of the 20/f weighted reading in dBrn. Read the unweighted amperes at the point the straight edge intersects the right vertical scale. Enter this value in column (10).



Courtesy Wilcom Products, Inc. FIGURE 9

NOMOGRAPH FOR DETERMINING EARTH RETURN CURRENT

4.3.4.1 There will be combinations of distance and readings where the straight edge will project beyond the limits of the right vertical scales. Where the scale indicates a value over 100 subtract 20 dB from the reading and realign the straight edge. Multiply the I value thus obtained by 10 to obtain the true current in amperes.

4.3.4.2 When the current value is less than 1 ampere or the 20/f reading is less than 8 dBrnc add 20 dB to the reading and realign the straight edge. If the straight edge intersects the right vertical scale divide the I value by 10 to obtain the current in amperes. When the straight edge indicates a value still less than 1 ampere add 40 dB to the original reading and realign the straight edge. Divide the I value thus obtained by 100 to obtain the current in amperes. As an example assume a distance of 18 feet and a reading of 0 dBrn. When 20 is added to the 0 reading and the straight edge is laid between 18 and 20 it is still off scale. By adding 40 to the 0 reading, the straight edge can be laid between 18 and 40 giving a reading of 8.5 on the right hand vertical scale. Dividing this by 100 gives 0.085 amperes which is usually rounded to 0.1 ampere.

4.3.5 Flat weighted readings can be converted to unweighted amperes directly by use of the nomograph shown in Figure 10. Enter the nomograph in the left vertical scale at the point of average distance between the center of the exploring coil and the power conductors. Lay a straight edge from this point on the center vertical scale of the flat weighted reading in dBrn. Read the value at the point the straight edge intersects the right vertical scale. Divide this value by the order of the harmonic (1, 2, 3, . . .) to obtain the unweighted earth return current.

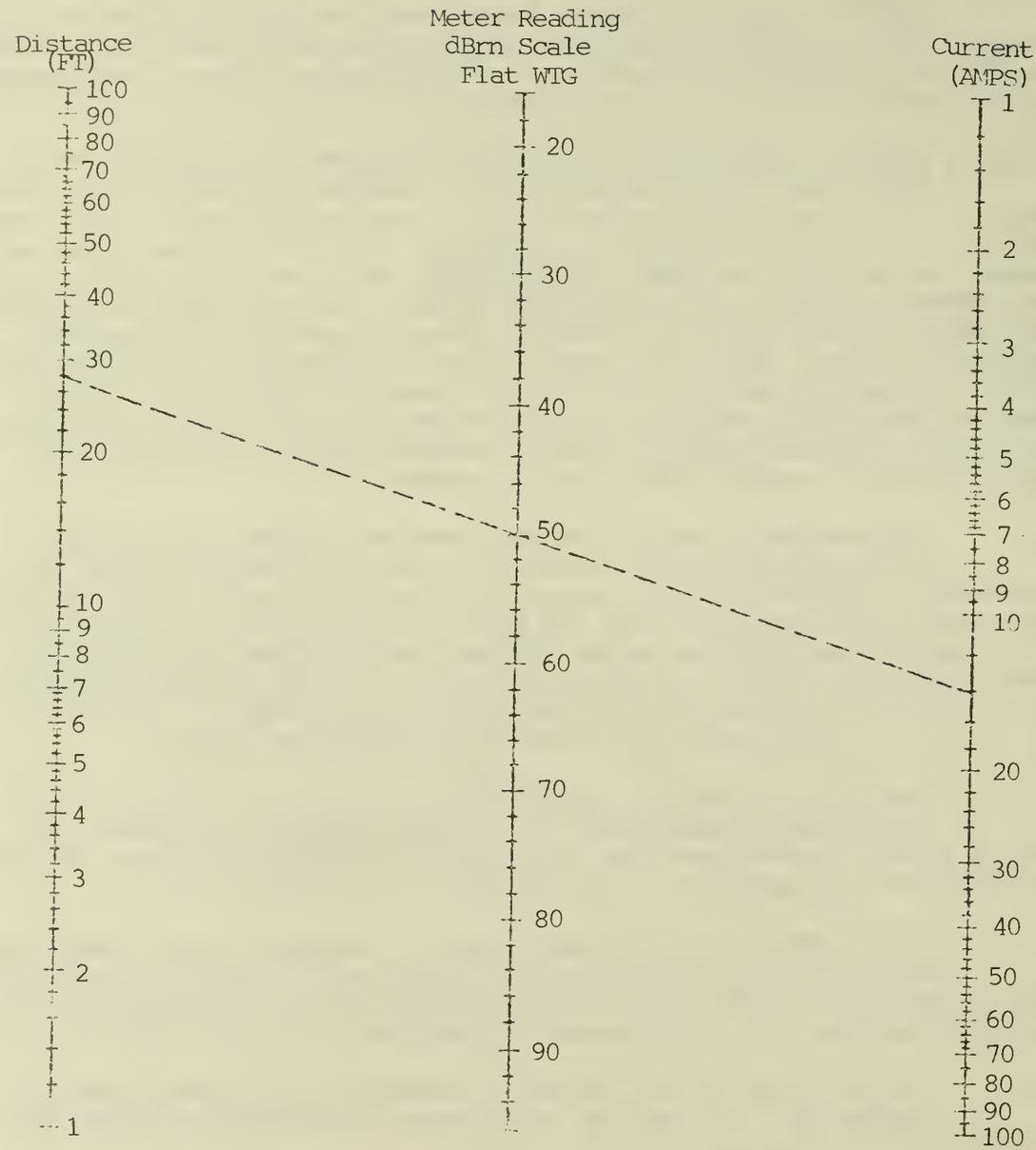
4.3.5.1 Overall earth return current cannot be calculated from an overall flat weighted measurement in the noise measuring set mode. The overall earth return current can be determined by finding the root sum square of the individual harmonic currents as shown in Paragraph 4.2.4.

4.3.5.2 The procedure to be followed where the straight edge extends beyond the limits of the right vertical scale or the reading is above or below those shown on the center vertical scale is the same as that for 20/f weighted readings. It is discussed in Paragraph 4.3.4.1 and 4.3.4.2.

4.3.6 The operation can be checked by determining the power summation of columns (6), (8), and (9) and the root sum square of column (10) as discussed in Paragraph 4.2.4.

4.3.7 The calculated values should be nearly equal to the overall measured values in the noise measuring set mode. A large discrepancy indicates an error in either the calculations or in the single frequency measurements. This should be found and corrected before proceeding further.

4.4 The final step is to calculate the TIF contribution of the earth return current. Subtract the 20/f reading in dBrn in column (8) from the C-MSG reading in column (3) and add 40 to the result. Enter the resulting TIF weighted dB ((T_f) dB) in column (11).



Courtesy Wilcom Products, Inc. FIGURE 10

NOMOGRAPH FOR DETERMINING EARTH RETURN CURRENT-FLAT WEIGHTED READING

4.4.1 Numerical TIF can be calculated by the equation:

$$\text{Numerical TIF} = \log^{-1}\left(\frac{(T_f)\ dB}{20}\right)$$

4.4.2 The numerical TIF can also be determined from the curve shown in Figure 11. Enter the bottom horizontal scale at the calculated (T_f) dB value from column (11) of the analysis form. Follow the vertical line to the point it intersects the curve. Read the TIF value of that point on the left vertical scale. Enter this value in column (12).

4.4.3 Numerical TIF may also be calculated by dividing the TIF weighted amperes from column (5) by the unweighted amperes from column (10).

4.4.4 Calculations should be completed for all individual frequencies and overall measured and calculated values. The TIF values recorded for the harmonic frequencies should agree with the values shown in Table III, Power Harmonic TIF Weighting Factors, TE&CM Section 452.

4.5 An example of a completed form for power system current wave for analysis is shown in Figure 12. It is important that all of the information at the top of the form be provided. The time may indicate the data was obtained during a period of low or high load demand. This can sometimes be valuable during the analysis. Weather conditions can have a direct relation to interference levels.

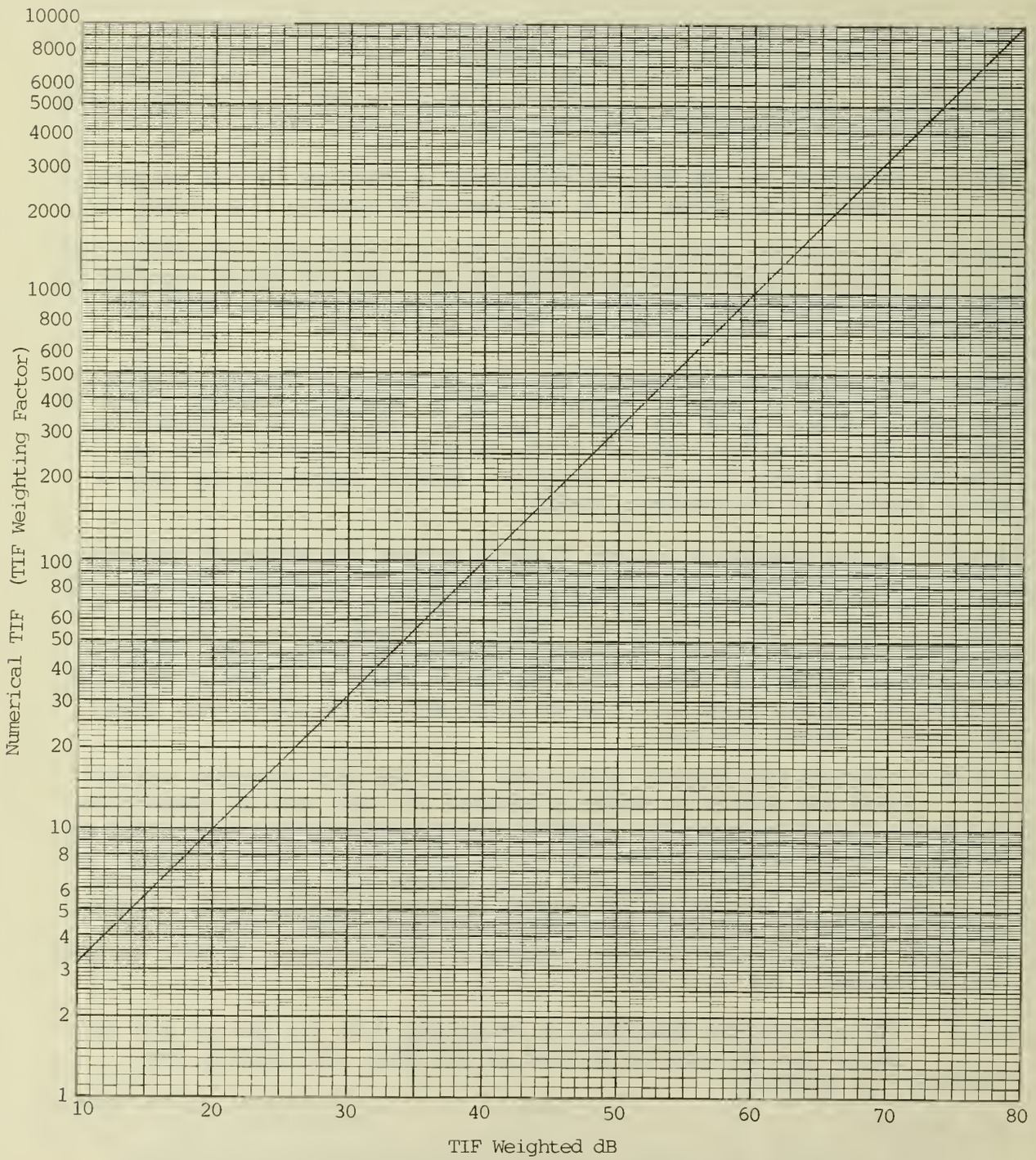
4.5.1 In the example an average distance between the center of the coil and the power conductors of 31 feet will be assumed. Enter this at (1) in the form. Looking at the table of height correction factors for an exploring coil at the bottom of the form a correction factor of 23 dB is found for a 30 foot height. Enter this value at (2) in the form. While a more precise correction factor (23.2 dB) can be found in Figure 16 of TE&CM Section 452 the resulting deviation is small and has no significant effect on the final values obtained.

4.5.2 Complete measurements with C-MSG, FLAT and 20/f weighting and record the results as shown in columns (3), (6), and (8) respectively for the listed frequencies. Complete overall measurements with a NMS and record in the designated spaces. It is not necessary to record readings at the higher harmonic frequencies when it is obvious they are at a low level which will have no bearing on the overall telephone circuit noise. Readings with 20/f weighting cannot be made accurately below 0dBrn. 20/f values should be calculated from recorded results of FLAT readings for 20/f weighted results between 0 and -13.5 dB.

4.5.3 The calculations described in Paragraphs 4.2, 4.3 and 4.4 are completed and the results entered on the form. All data is now available for analysis.

5. ANALYSIS

5.1 The results from measurements in the NMS mode in column (10) of Figure 12 shows an overall earth return current of about 4.2 amperes. This indicates there is little likelihood of a fundamental frequency problem (excessive longitudinal 60 Hertz voltage in the telephone system). Generally when the overall earth return current approaches or exceeds 20 amperes there is a possibility of a fundamental frequency voltage problem. The IT (TIF weighted amperes) value in column (5) is 1189 indicating that there is a



CONVERSION CURVE
TIF WEIGHTED dB TO
NUMERICAL TIF
FIGURE 11

possibility that the earth return current of one or more harmonic frequencies may be high enough to induce noise in a well balanced telephone circuit.

5.1.1 It is difficult to establish the precise I·T value which will indicate a noise problem exists. The overall I·T provides a broad indication of the potential interference from a power line. Normally the I·T is not measured unless a noise problem exists and the telephone company has eliminated all potential problem areas in its system. There are situations as discussed in Paragraph 1.1 where these measurements might be completed before a problem is known to exist. As a general rule when the I·T exceeds 1000 a harmonic analysis of the earth return current should be completed.

5.1.2 The I·T values for each harmonic frequency in column (5) of the example are acceptable except for 540 Hertz which is 1000. This indicates there is a potential for telephone system noise at this frequency. As a general rule if the I·T at any individual frequency exceeds 500 there is a possibility of a noise problem in parallel telephone circuits. This does not however guarantee a noise problem cannot occur when the I·T is less than 500 but that there is a lower probability of one occurring. There are other variable contributing factors such as the length of exposure, separation between the telephone and power lines, etc. (See TE&CM Section 452, Paragraph 5).

5.2 The unweighted harmonic frequency earth return current values in column (10) show there may be significant current at four frequencies. They are 180, 300, 420, and 540 Hertz with currents of 0.7, 0.6, 0.6 and 0.7 amperes respectively. There is little chance of 180 or 300 Hertz contribution to the noise problem due to the low I·T. There is a possibility that the 420 Hertz component might be contributing to the telephone system noise if there is a long exposure. The 540 Hertz component appears to be the principal contributor in this case. When long exposures are involved 540 Hertz earth return currents of 0.1 ampere should not be disregarded as insignificant. A substantial longitudinal voltage can be induced in the telephone system which should not be considered a power system problem since the I·T would only be 132. (See TE&CM Section 452, Paragraph 5).

5.3 The numerical TIF values from column (12) show good correlation to those from Table III of TE&CM Section 452.

Frequency	Column (12)	Table III
180 Hertz	29	30
300 Hertz	224	225
360 Hertz	380	400
420 Hertz	624	650
480 Hertz	955	950
540 Hertz	1349	1329

5.4 The differences between numerical TIF and Table 3 values are to be expected as are those between overall NMS measurements and power summations. They occur since it is not possible to complete all measurements at the same instant. During the time required to complete the measurements

REA TE&CM 452.2

POWER SYSTEM CURRENT WAVE FORM ANALYSIS

Central Office ALPHA

Power Company BETA ELECTRIC Sheet No. 1

Primary Voltage 7.62 kV. 3-Phase Date 6/1/75

Test Location Adjacent to Pedestal A1-5 A1 Route Time 2:30 P.M

Test Condition Clear and Hot Tester Doc

☐ 100 foot probe wire ☒ Exploring coil type: CCS-105

Power Line Height (Average) 31 Feet (1); Correction Factor 23.0 dB (2)

FREQ. Hz.	Harmonic	TIF Weighted (Weighing Switch in C-MSG.)			Unweighted (Weighing Switch in 50 KHZ-FLAT or 20/F)					TIF Contribution	
		Reading dB (3)	(2)+(3) $I_f \cdot W_f$ dBA (4)	$I_f \cdot W_f$ wtd. amps (5)	Flat Reading dB (6)	20/f Factor (7)	(6)+(7) or 20f Reading (8)	(8)+(2) -40 dB =(If)dBA (9)	I_f amps (10)	(3)-(8) +40 dB =(T_f) dB (11)	T_f (12)
60	1	-			38.0	-9.5	28.5	11.5	3.8		
120	2	-			8.0	-15.6	-7.6	-24.6	0.1		
180	3	3.0	26.0	20	33.0	-19.1	13.9	-3.1	0.7	29.1	29
240	4	-			-	-21.6	-				
300	5	19.0	42.0	126	35.5	-23.5	12.0	-5.0	0.6	47.0	224
360	6	-2.0	21.0	11	11.5	-25.1	-13.6	-30.6	-	51.6	380
420	7	28.0	51.0	355	38.5	-26.4	12.1	-4.9	0.6	55.9	624
480	8	1.0	24.0	16	9.0	-27.6	-18.6	-35.6	-	59.6	955
540	9	37.0	60.0	1000	43.0	-28.6	14.4	-2.6	0.7	62.6	1349
600	10	1.0	24.0	16	5.5	-29.5					
660	11	7.0	30.0	32	10.0	-30.4					
720	12	6.0	29.0	28	8.5	-31.1					
780	13	16.0	39.0	89	17.5	-31.8					
840	14	1.0	24.0	16	2.0	-32.5					
900	15	14.0	37.0	71	14.0	-33.1					
960	16	-			-	-33.6					
1020	17	-1.0	22.0	13	-1.0	-34.2					
1140	19	20.0	43.0	141	20.0	-35.1					
1260	21	-1.0	22.0	13	-1.0	-36.0					
1380	23	11.0	34.0	50	12.0	-36.8					
1500	25	9.0	32.0	40	10.0	-37.5					
1620	27	4.0	27.0	22	5.0	-38.2					
1740	29	6.0	29.0	28	7.0	-38.8					
1860	31	2.0	25.0	18	3.0	-39.4					
1980	33					-40.0					
2100	35					-40.4					
2220	37					-40.9					
2340	39					-41.4					
2460	41					-41.8					
2580	43					-42.2					
2700	45					-42.6					
2820	47					-43.0					
2940	49					-43.3					
3060	51					-43.7					
3180	53					-44.0					
			(I·T)dB	I·T				(I) dBA	I	(TIF)dB	TIF
PWR SUM		37.7	60.7	1088	45.9		29.0	12.0	4.0	48.7	272
NMS		38.5	61.5	1189	46.5		28.5	12.5	4.2	49.0	282

		Height of Power Line Above Probe Wire or Coil								
		20'	25'	30'	35'	40'	45'	50'	55'	60'
Height Correction Factor dB	100' Probe Wire	0.5	1.1	1.6	2.1	2.5	2.9	3.3	3.6	3.9
	Exploring Coil	19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

FIGURE 12

EXAMPLE - INITIAL MEASUREMENTS -- EARTH RETURN CURRENT

there will be variations in the power system loads producing these minor differences.

5.5 The 540 Hertz component is the predominant harmonic in the majority of noise investigations. Power line resonance is often a factor which can be further aggrevated by capacitor bank installations. A capacitor bank located on the field side of the location of the measurements shown in the example (Figure 12) will be assumed. This bank can be suspected of contributing to the noise problem.

5.6 Additional measurements of the harmonic frequency earth return current should be made at locations along the power line both directions from the capacitor bank. It will be assumed that the recorded results of these measurements at a location on the field side of the capacitor bank show an I·T of 442 at 540 Hertz and an earth return current of 0.3 amperes. This provides further confirmation that the capacitor bank is a major contributor to the noise problem.

5.7 At this point the power company should be contacted. Enough information has been accumulated to determine that a condition in the power line operation is apparently the principal source of the telephone system noise. The information is in units (I·T and I) which will assist a power company engineer in making decisions regarding possible actions to relieve the problem. Even when the telephone engineer or technical has made some assumptions relative to the noise contribution from various power system components the final determination should be left to the power company.

5.7.1 Present all of the earth return data to the power company together with additional information showing that telephone shields are continuous and the telephone circuits have excellent balance. Negotiate an agreement with the power company to temporarily remove the ground connection from the capacitor bank. During the period the ground connection is removed the telephone company repeats the original measurements near the capacitor bank.

5.7.2 It will be assumed for the example that the recorded results of power system earth return current measurements with the capacitor bank ground connection removed are those shown in Figure 13. The I·T at 540 Hertz has been reduced from 1000 to 22. The earth return current could not be measured although calculations determined it was now about 0.016 ampere. The I·T of the 420 Hertz component has been reduced from 355 to 335 and the earth return current from 0.6 to 0.5. Noise measurements should be made at the subscriber location with the capacitor bank ground removed. It will be assumed that the 420 Hertz component is not a significant factor in the overall noise.

5.7.3 Recorded results of noise measurements at the subscriber residence are: Power Influence, 89.2 dBrnc and Circuit Noise, 12.5 dBrnc giving a balance of 76.7 dB. Even though the power influence is still in the marginal range there has been a marked reduction from the results of the original measurements made at the same location with the capacitor bank connected to ground. Original measurements were: Power Influence, 105.5 dBrnc and Circuit Noise, 28.0 dBrnc giving a balance of 77.5 dB. This confirms the capacitor bank was the principal contributor to the noise problem.

POWER SYSTEM CURRENT WAVE FORM ANALYSIS

Central Office ALPHA

Power Company BETA ELECTRIC Sheet No. 2

Primary Voltage 7.62 kV. 3-Phase Date 6/2/75

Test Location Adjacent to Pedestal A1-5 A1 Route Time 10:30 am

Test Condition Clear and Hot Tester Doc

☐ 100 foot probe wire ☒ Exploring coil type: CCS-105

Power Line Height (Average) 31 Feet (1); Correction Factor 23.0 dB (2)

FREQ. Hz.	Harmonic	TIF Weighted (Weighing Switch in C-MSG.)			Unweighted (Weighing Switch in 50 KHZ-FLAT or 20/F)					TIF Contribution	
		Reading dB (3)	(2)+(3) $I_f \cdot W_f$ dBA (4)	$I_f \cdot W_f$ wtd. amps (5)	Flat Reading dB (6)	20/f Factor (7)	(6)+(7) or 20f Reading (8)	(8)+(2) -40 dB =(I_f)dBA (9)	I_f amps (10)	(3)-(8) +40 dB =(T_f) dB (11)	T_f (12)
60	1	-			37.0	-9.5	27.5	10.5	3.3		
120	2	-			7.0	-15.6	-8.6	-25.6	0.1		
180	3	-1.0	22.0	13.0	27.5	-19.1	8.4	-8.6	0.4	30.6	34
240	4	-			-5.0	-21.6	-26.6				
300	5	20.0	43.0	141	37.5	-23.5	14.0	-3.0	0.7	46.0	200
360	6	-3.0	20.0	10	10.0	-25.1	-15.1				
420	7	27.5	50.5	335	38.0	-26.4	11.6	-5.4	0.5	55.9	624
480	8	-1.0	22.0	13	7.0	-27.6					
540	9	4.0	27.0	22	10.0	-28.6					
600	10	-			-2.0	-29.5					
660	11	15.0	38.0	79	17.5	-30.4					
720	12	-			-5.0	-31.1			-		
780	13	17.4	40.4	105	18.2	-31.8					
840	14	-			-	-32.5					
900	15	12.5	35.5	60	13.0	-33.1					
960	16	-			-	-33.6					
1020	17	20.0	43.0	141	20.0	-34.2					
1140	19	19.0	42.0	126	19.0	-35.1					
1260	21	16.0	39.0	89	16.5	-36.0					
1380	23	15.0	38.0	78	15.5	-36.8					
1500	25	7.3	30.3	33	8.0	-37.5					
1620	27	-1.0	22.0	13	0	-38.2					
1740	29	8.8	31.8	39	9.8	-38.8					
1860	31	2.0	24.0	16	2.7	-39.4					
1980	33					-40.0					
2100	35					-40.4					
2220	37					-40.9					
2340	39					-41.4					
2460	41					-41.8					
2580	43					-42.2					
2700	45					-42.6					
2820	47					-43.0					
2940	49					-43.3					
3060	51					-43.7					
3180	53					-44.0					
			(I·T)dB	I·T				(I) dBA	I	(TIF)dB	TIF
PWR SUM		30.2	53.2	455	42.5		27.8	10.8	3.4	42.4	132
NMS		29.5	52.5	422	41.5		27.2	10.2	3.2	42.3	130

		Height of Power Line Above Probe Wire or Coil								
		20'	25'	30'	35'	40'	45'	50'	55'	60'
Height Correction Factor dB	100' Probe Wire	0.5	1.1	1.6	2.1	2.5	2.9	3.3	3.6	3.9
	Exploring Coil	19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

FIGURE 13
EXAMPLE - SECOND MEASUREMENT - EARTH RETURN CURRENT

5.7.4 Arrange another meeting with the power company representatives and present the new recorded data. Negotiate with the power company to obtain relief from the effects of the capacitor bank. While the final decision as to corrective action rests with the power company the telephone company representatives need to be aware of the options available. The effects of power system resonance which may be aggravated by capacitor banks can be reduced in several ways.

5.7.4.1 The capacitor bank can be relocated to a point closer to the substation. This reduces the cable length that is exposed to the high harmonic frequency earth return current. There are sometimes situations where the capacitor bank can be removed completely.

5.7.4.2 A harmonic shunt installed in the ground lead of the capacitor bank can be tuned to supress the interference of voice band harmonic frequencies. This technique has been quite effective in the field.

5.7.4.3 Some power companies will remove the ground connection permanently from the capacitor bank. While this technique can effectively reduce interference, there are some potential safety hazards involved. It is not, therefore, a recommended procedure.

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452.3

PROBE WIRE MEASUREMENTS

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DEPOSITORY
DEC 30 1980
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

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1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for using a probe wire during noise investigations. Probe wire investigations may be undertaken where the telephone plant has been operational for several years, where the telephone plant has just been placed and is not yet operational or along routes where construction of new telephone plant has been proposed.

1.2 A probe wire is used to measure the magnitude of the overall or individual harmonic frequency earth return current of a power line (See TE&CM Section 452, Paragraph 9.3).

1.3 A probe wire consists of a length of insulated wire and two ground rods. The wire may be two conductor lamp cord with the two conductors shorted together at each end. A one hundred foot probe wire is

the length most commonly used. When measurements are made at a distance from the power line, such as along a HVDC transmission line, a probe wire length of up to five hundred feet may be used. The ground rods are usually the same type used for station protection at subscriber premises.

1.4 Earth return current is usually measured along a power line after it has been determined that circuit noise in a telephone system cannot be reduced to an acceptable level through further work on the telephone plant. In other words, cable balance is excellent, cable shield continuity has been verified by measurement and the source of noise is through induction. Another situation where the measurement of power system earth return current might be desirable is where a new cable extension is planned parallel to an existing power line. The expected power influence can be calculated from the average earth return current as determined from measurements of earth return current along the power line. Thus if it is found that a neutralizing transformer is required, it can be included in the transmission design or the proposed routing changed.

1.5 The technique for measuring power line earth return currents is effective on single-, two-, or three-phase power systems. As with any measurement technique it is important that the user be aware of limitations and/or problems relating to its use.

1.5.1 A probe wire measurement requires more time to set up and complete than does an exploring coil measurement. It is necessary to lay the probe wire on the ground and drive two ground rods.

1.5.2 The resulting earth return value is influenced by differences in potential along the earth surface. These differences in potential are produced by earth currents from sources such as metallic fences, buried pipes, etc.

2. MEASUREMENT OF EARTH RETURN CURRENT

2.1 The selection of a location for measurement of power line earth return currents is an important consideration. It must be free from factors that might produce erroneous results. Things to avoid are:

2.1.1 Power line spans that include secondary distribution conductors should be avoided. The presence of secondary distribution conductors alters the magnetic field and can cause significant error in the results of earth return measurements.

2.1.2 Discontinuities in the power line such as bridged taps, distribution transformers, power factor correction capacitors corners or dead-ends should also be avoided. These will distort the magnetic field from the power line and cause errors in earth return current measurements.

2.1.3 Metal fences located beneath or near a power line and parallel to it should be avoided. The magnetic field from a grounded metal fence may be stronger at the earth's surface than that from the power line. This could result in a large error in earth return current measurements.

2.1.4 Sections where power and telephone lines share poles should be avoided unless the joint-use extends through the entire exposure. Recorded results of measured earth return current are not the true values where the entire exposure is in joint-use. The error is due to the cable's location near the power conductors. Variations in earth return current along the power line and the predominant harmonics of the fundamental frequency can still be determined.

2.1.5 A probe wire should not be used where a buried cable or metallic pipe line is located beneath or very near the power line. The magnetic field from either of these may be stronger than that from the power line at the earth's surface. This will produce erroneous results.

2.2 After the site has been selected for the measurements estimate the distance to the lowest wire of the power line. Enter this value in the appropriate space (1) on the form for power system wave form analysis. A sample form for recording the data is shown in Figure 1. The sample form is designed for use when measuring power system earth return currents with either a probe wire or an exploring coil (See TE&CM Section 452.2).

2.2.1 Find the height correction factor when a 100 foot probe wire is used in the table at the bottom of the analysis form for the estimated power line height and enter it in the appropriate space. The correction factors were derived by the equation:

$$\text{Correction Factor} = 20 \log M + 94.2$$

Where:

$$M = 0.14 \times 10^{-6} \ell \times \log \left(\frac{(400 + D)}{D} \right) \text{ Henries}$$

With:

ℓ = Length of probe wire in feet
D = Distance between lowest power conductor and probe wire in feet

2.2.2 When using probe wires other than 100 feet in length or where distance between the probe wire and power conductor exceeds 60 feet new correction factors will have to be computed by the equation in Paragraph 2.2.1. Change the sign of the calculated correction factor before entering it in the analysis form.

POWER SYSTEM CURRENT WAVE FORM ANALYSIS

Central Office _____

Power Company _____ Sheet No. _____

Primary Voltage _____ Date _____

Test Location _____ Time _____

Test Condition _____ Tester _____

☐ 100 foot probe wire _____ ☐ Exploring coil type: _____

Power Line Height (Average) _____ Feet (1); Correction Factor _____ dB (2)

FREQ. Hz.	Harmonic	TIF Weighted (Weighing Switch in C-MSG.)			Unweighted (Weighing Switch in 50 KHZ-FLAT or 20/F)					TIF Contribution	
		Reading dB (3)	(2)+(3) $I_f \cdot W_f$ dBA (4)	$I_f \cdot W_f$ wtd. amps (5)	Flat Reading dB (6)	20/f Factor (7)	(6)+(7)or 20f Reading (8)	(8)+(2) -40 dB =(If)dBA (9)	I_f amps (10)	(3)-(8) +40 dB =(T_f) dB (11)	T_f (12)
60	1					-9.5					
120	2					-15.6					
180	3					-19.1					
240	4					-21.6					
300	5					-23.5					
360	6					-25.1					
420	7					-26.4					
480	8					-27.6					
540	9					-28.6					
600	10					-29.5					
660	11					-30.4					
720	12					-31.1					
780	13					-31.8					
840	14					-32.5					
900	15					-33.1					
960	16					-33.6					
1020	17					-34.2					
1140	19					-35.1					
1260	21					-36.0					
1380	23					-36.8					
1500	25					-37.5					
1620	27					-38.2					
1740	29					-38.8					
1860	31					-39.4					
1980	33					-40.0					
2100	35					-40.4					
2220	37					-40.9					
2340	39					-41.4					
2460	41					-41.8					
2580	43					-42.2					
2700	45					-42.6					
2820	47					-43.0					
2940	49					-43.3					
3060	51					-43.7					
3180	53					-44.0					
			(I·T)dB	I·T				(I) dBA	I	(TIF)dB	TIF
PWR SUM											
NMS											

		Height of Power Line Above Probe Wire or Coil								
		20'	25'	30'	35'	40'	45'	50'	55'	60'
Height Correction Factor dB	100' Probe Wire	0.5	1.1	1.6	2.1	2.5	2.9	3.3	3.6	3.9
	Exploring Coil	19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

FIGURE 1

2.3 Drive a ground rod at one end of the selected location. Connect one end of the insulated probe wire to the ground rod and extend it along the surface of the ground parallel to the power line as shown in Figure 2 for its full length. Drive a second ground rod at that end of the probe wire. Connect the probe wire to the tip terminal of the spectrum analyzer and with a short length of wire connect the second ground rod to the ring terminal. The spectrum analyzer must have a high input impedance; 100,000 ohms or more.

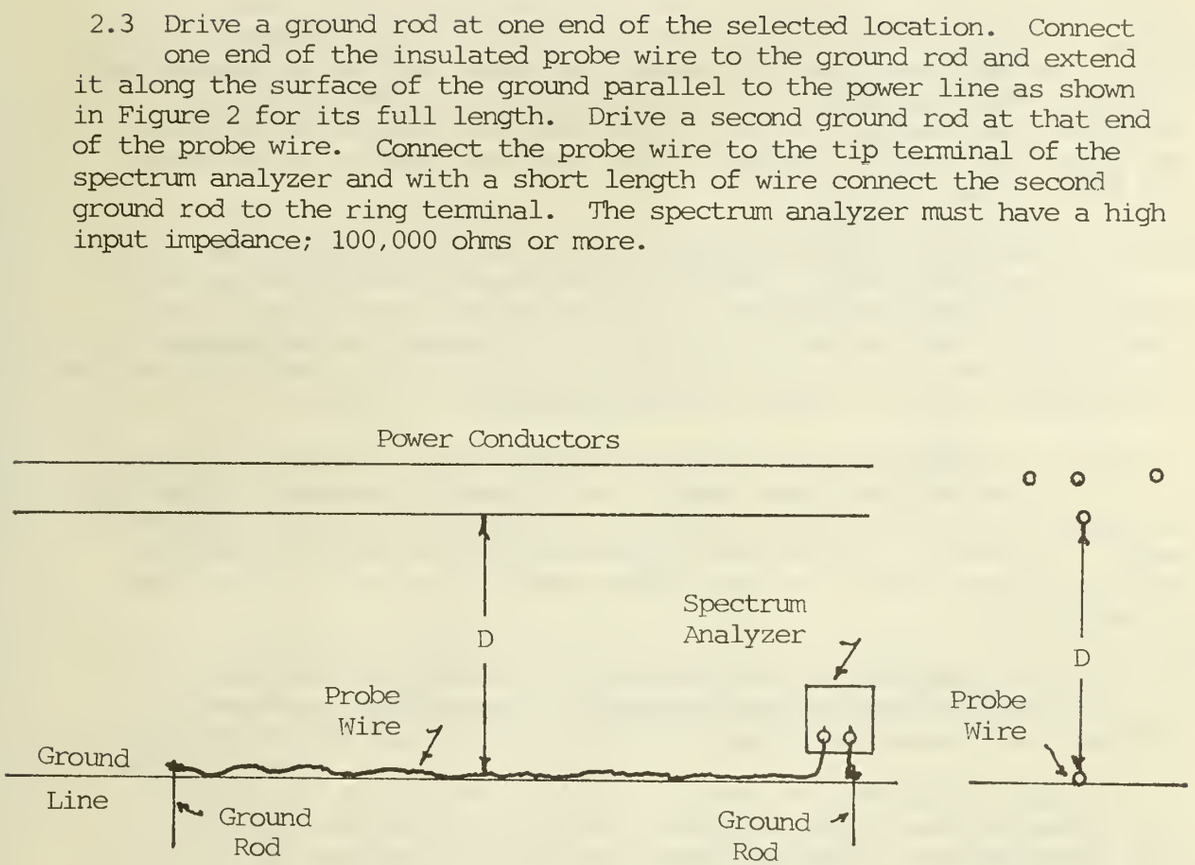

FIGURE 2
PROBE WIRE CONFIGURATION

2.3.1 When using a spectrum analyzer designed for telephone system measurements set function switch to the BRDG600 position. Place the weighting switch to the desired weighting (C-MSG, 50 kHz FLAT or 20/f).

2.3.1.1 A 50 kHz FLAT weighting filter may not be available on all test equipment. The 3 kHz FLAT weighting should not be used for these measurements since it may prove necessary to measure frequencies higher than the filter cutoff frequency.

2.3.1.2 For analysis on test equipment that does not have a 20/f weighting filter, factors for 20/f weighting in dBrn have been included in column (7) of the sample form shown in Figure 1. 20/f weighted values are derived by adding 20/f weighting factors to the recorded flat weighted readings.

2.3.2 Successively set the spectrum analyzer to the frequencies listed on the form. Read and record the values in dBrnc on the analysis form for each frequency with the weightings shown. When using test equipment that does not have 20/f weighting the values will have to be calculated from recorded values of flat weighted readings as shown on the form. (See Paragraph 3).

2.3.2.1 Switch the operating mode from spectrum analysis to NMS (noise measuring set). Make an overall reading with C-MSG and 20/f weighting. Record the results in the appropriate spaces of the form. These overall readings may be converted to numerical overall values of TIF weighted amperes (I·T) and amperes (I) respectively (See TE&CM Section 452) because they are independent of frequency.

2.3.2.2 An overall flat weighted measurement does not have to be made. Flat weighted measurements are frequency dependent and can only be converted to earth return current (I) when made on a single frequency basis. An overall flat weighted measurement can be used to check the accuracy of the single frequency measurements. This will be discussed in Paragraph 4.

2.3.3 This completes the measurements at a location. Move to the next location that has been selected and repeat the procedures. Continue until measurements have been completed at all desired sites.

2.4 Should measurements be desired along a route where there is no location that does not have buried cable, buried pipeline or a wire fence directly below the power line place the probe wire 50 to 100 feet away from the power line. Then repeat the procedures for measurement starting at Paragraph 2.2. This will place the probe wire beyond the influence of the buried cable, buried pipeline or fence.

3. CALCULATION OF EARTH RETURN CURRENT

3.1 Numerical values of TIF weighted amperes (I·T) and amperes (I) are calculated as shown on the form for power system current wave form analysis (Figure 1).

3.2 The first step is to convert C-MSG weighted readings in column (3) to TIF weighted dB by adding the correction factor at (2) to the reading and enter the result in the I_f , W_f dBA column (4) of the form (Figure 1). Complete this operation for each frequency and for the overall NMS reading.

3.2.1 Calculated TIF weighted amperes by the equation:

$$I \cdot T = \log^{-1}\left(\frac{(I_f \cdot W_f \text{ dBA})}{20}\right)$$

3.2.2 TIF weighted amperes may also be determined from the curve shown in Figure 3. Enter the bottom horizontal scale at the calculated $I_f \cdot W_f$ dBA value from column (4) of the analysis form. Follow the vertical line to the point it intersects the curve. Read the TIF weighted amperes (I·T) of that point on the left vertical scale. Enter value in column (5).

3.2.3 Work can be checked by calculating the power summation of columns (3) and (4) and the root sum square (RSS) of column (5). Root sum square is the square root of the sum of the squares of the individual values. Results of power summations are in decibels and results of root sum squares are in numeric units.

3.2.3.1 The equation for power summation is:

$$\text{PWR SUM} = 10 \log \left(\Sigma \log^{-1} \left(\frac{\text{dB}}{10} \right) \right)$$

3.2.3.2 The equation for root sum square is:

$$\text{RSS} = \sqrt{\Sigma I^2}$$

3.2.4 Calculated values should be nearly equal to the overall measured values in the noise measuring set mode. A large discrepancy indicates an error in either the calculations or in the individual single frequency measurements. This should be found and corrected before proceeding further.

3.3 The next step is to determine the magnitude of the unweighted earth return current. If the measurements were made with equipment not having a 20/f filter, only the recorded results of flat weighted measurements will be available. Convert the results of the flat weighted readings to 20/f values by adding the 20/f weighting factors from column (7) of the analysis form to the recorded flat readings in column (6). Enter the resulting values in column (8). Flat weighted overall readings cannot be converted to 20/f values since there is no single 20/f factor that can be applied.

3.3.1 When recorded 20/f weighted values are available, either calculated or measured, calculate the unweighted earth return current in I_f dBA. Add the correction factor (2) from the analysis form to the recorded 20/f weighted value from column (8) and subtract 40 from the result. Enter this value of the unweighted current in dBA in column (9). Complete this operation for each frequency and for the overall NMS readings.

3.3.2 The unweighted earth return current in amperes is calculated from the equation:

$$I_f = \log^{-1} \left(\frac{(I_f)\,\text{dBA}}{20} \right)$$

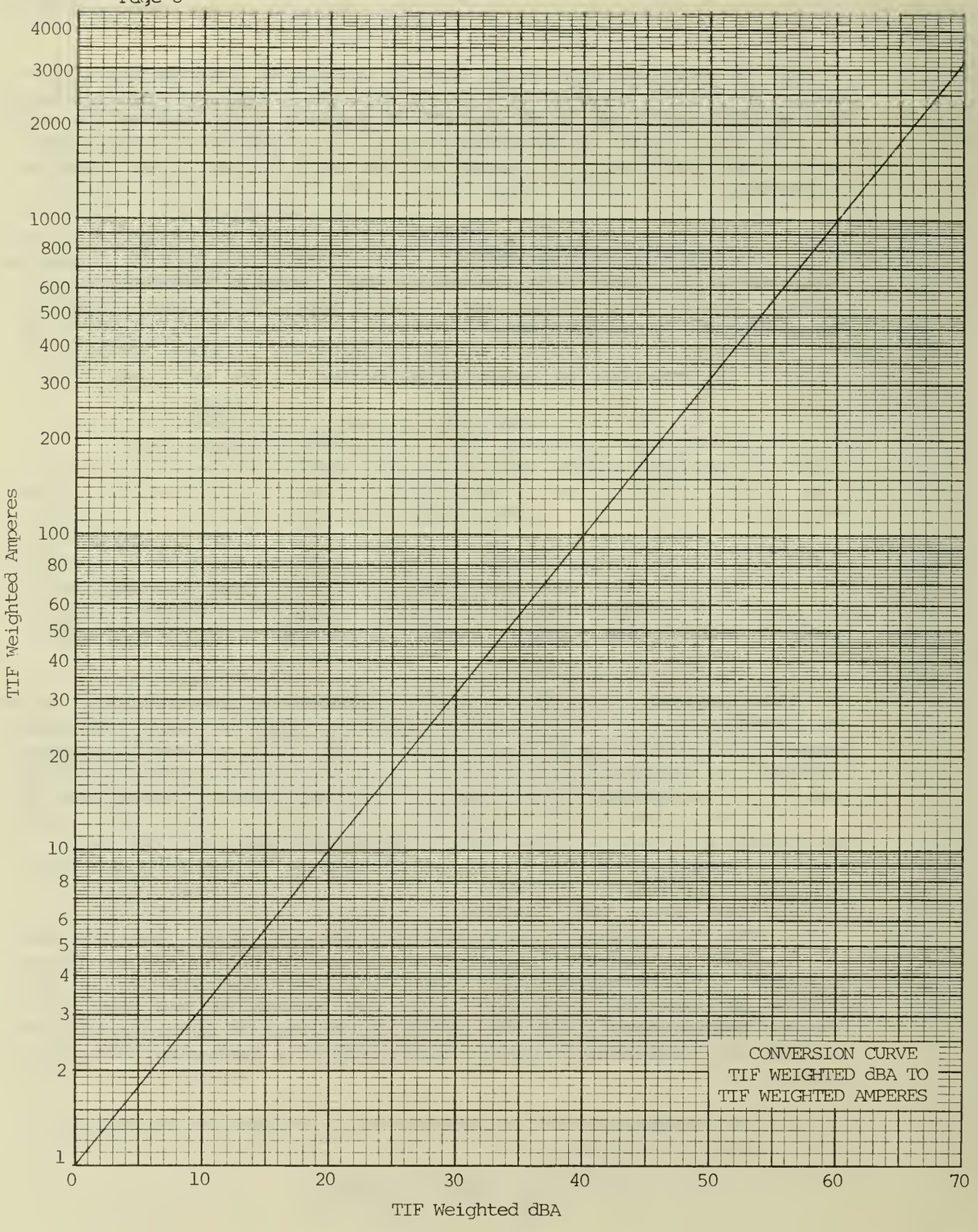
4000
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
2
1
TIF Weighted Amperes
0
10
20
30
40
50
60
70
TIF Weighted dBA
CONVERSION CURVE
TIF WEIGHTED dBA TO
TIF WEIGHTED AMPERES

FIGURE 3

3.3.3 The unweighted ampere value may also be determined from the curve shown in Figure 4. Enter the bottom horizontal scale at the calculated (I_f) dBA value from column (9) of the analysis form. Follow the vertical line to the point it intersects the curve. Read the value of unweighted amperes (I) of that point on the left vertical scale. Enter this value in column (10).

3.3.4 The operation can be checked by determining the power summation of columns (6), (8), and (9) and the root sum square as discussed in Paragraph 3.2.3.

3.3.5 The calculated values should be nearly equal to the overall measured values in the noise measuring set mode. A large discrepancy indicates an error in either the calculations or in the single frequency measurements. This should be found and corrected before proceeding further.

3.4 The final step is to calculate the TIF contribution of the earth return current. Subtract the 20/f reading in dBrn in column (8) from the C-MSG reading in column (3) and add 40 to the result. Enter the resulting TIF weighted dB ((T_f)dB) in column (11).

3.4.1 Numerical TIF can be calculated by the equation:

$$\text{Numerical TIF} = \log^{-1}\left(\frac{(T_f)\text{dB}}{20}\right)$$

3.4.2 The numerical TIF can also be determined from the curve shown in Figure 5. Enter the bottom horizontal scale at the calculated (T_f)dB value from column (11) of the analysis form. Follow the vertical line to the point it intersects the curve. Read the TIF value of that point on the left vertical scale. Enter this value in column (12).

3.4.3 Numerical TIF may also be calculated by dividing the TIF weighted amperes from column (5) by the unweighted amperes from column (10).

3.4.4 Calculations should be completed for all individual frequencies and overall measured and calculated values. The TIF values recorded in column (12) should be nearly equal to the values shown in Table III, Power Harmonic TIF Weighting Factors, TE&CM Section 452.

3.5 An example of a completed form for power system current wave form analysis is shown in Figure 6. It is important that all of the information at the top of the form be provided. The time may indicate the data was obtained during a period of high or low load demand. This can sometimes be valuable during the analysis. Weather conditions can have a direct relationship to interference levels.

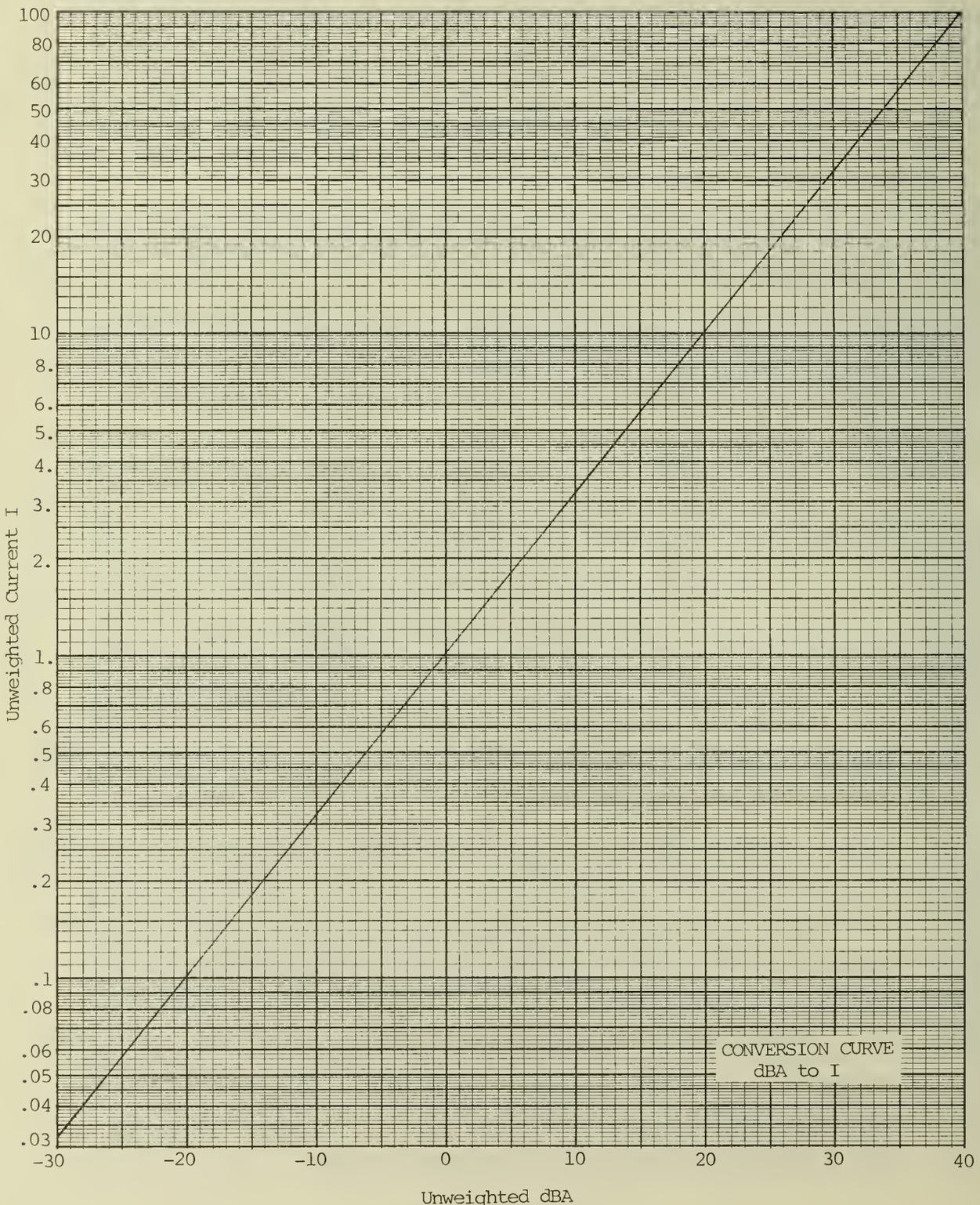
100
80
60
50
40
30
20
10
8.
6.
5.
4.
3.
2.
1.
.8
.6
.5
.4
.3
.2
.1
.08
.06
.05
.04
.03
Unweighted Current I
-30
-20
-10
0
10
20
30
40
Unweighted dBA
CONVERSION CURVE
dBA to I

FIGURE 4

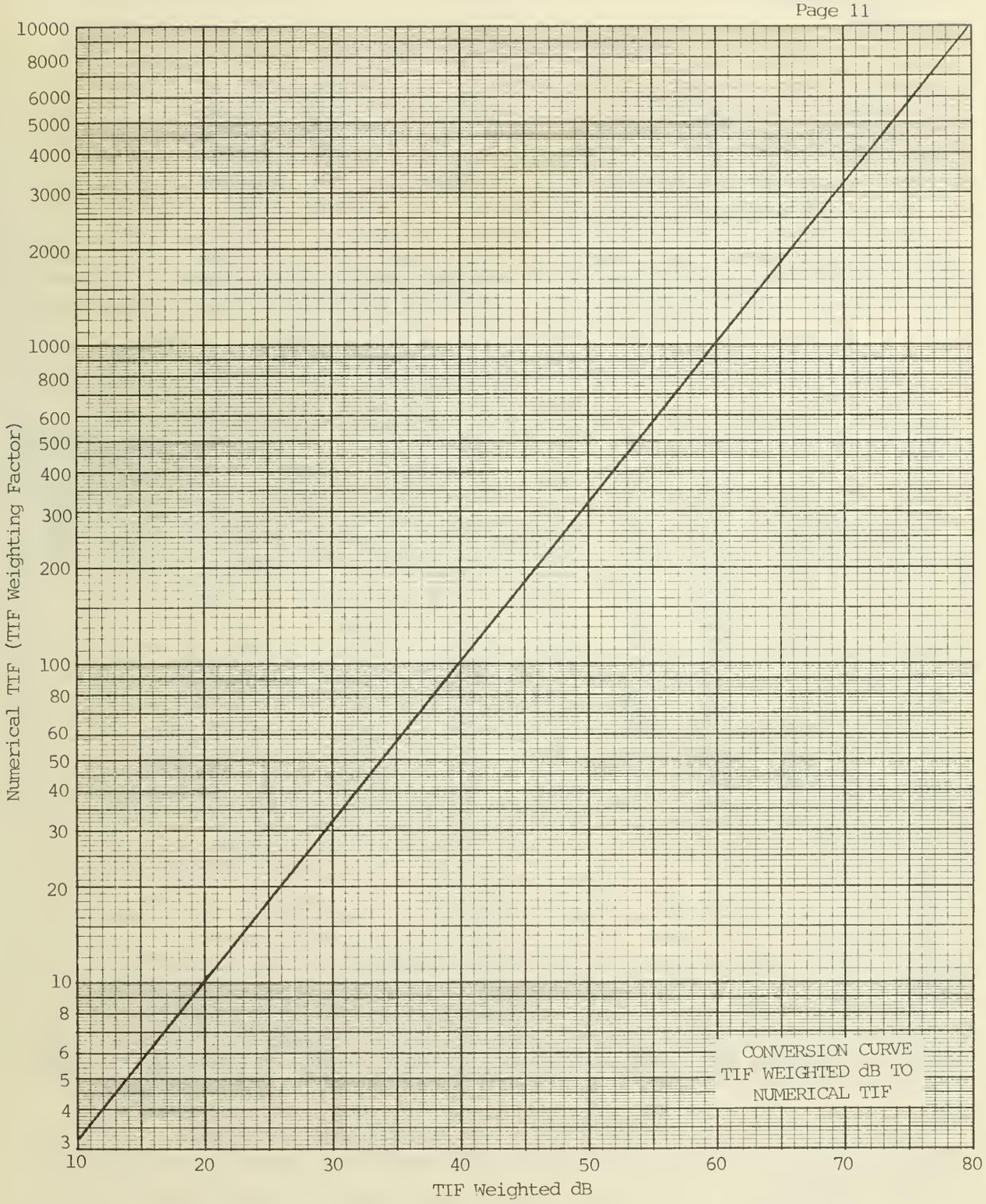
Numerical TIF (TIF Weighting Factor)
10000
8000
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
8
6
5
4
3
10
20
30
40
50
60
70
80
TIF Weighted dB
CONVERSION CURVE
TIF WEIGHTED dB TO
NUMERICAL TIF

FIGURE 5

POWER SYSTEM CURRENT WAVE FORM ANALYSIS

Central Office ALPHA

Power Company BETA ELECTRIC Sheet No. 1

Primary Voltage 7.62 kV. 3-Phase Date 6/1/75

Test Location Adjacent to Pedestal A1-5 A1 Route Time 2:30pm

Test Condition Clear and Hot Tester Doc

☒ 100 foot probe wire ☐ Exploring coil type:

Power Line Height (Average) 31 Feet (1); Correction Factor 1.6 dB (2)

FREQ. Hz.	Harmonic	TIF Weighted (Weighing Switch in C-MSG.)			Unweighted (Weighing Switch in 50 KHZ-FLAT or 20/F)					TIF Contribution	
		Reading dB (3)	(2)+(3) $I_f \cdot W_f$ dBA (4)	$I_f \cdot W_f$ wtd. amps (5)	Flat Reading dB (6)	20/f Factor (7)	(6)+(7) or 20f Reading (8)	(8)+(2) -40 dB =(If)dBA (9)	I_f amps (10)	(3)-(8) +40 dB =(T_f) dB (11)	T_f (12)
60	1	-			59.5	-9.5	50.0	11.6	3.8		
120	2	-			29.4	-15.6	14.0	-24.4	0.1		
180	3	24.5	26.1	20	54.1	-19.1	35.0	-3.4	0.7	29.5	30.0
240	4	-			-	-21.6	-				
300	5	40.5	42.1	127	57.0	-23.5	33.5	-4.9	0.6	47.0	224
360	6	19.5	21.1	11	33.1	-25.1	8.0	-30.4	-	51.5	376
420	7	49.5	51.1	359	59.9	-26.4	33.5	-4.9	0.6	56.0	631
480	8	22.5	24.1	16	30.4	-27.6	2.8	-35.6	-	59.7	966
540	9	58.5	60.1	1012	64.4	-28.6	35.8	-2.6	0.7	62.7	1365
600	10	22.5	24.1	16	26.9	-29.5			-		
660	11	28.5	30.1	32	31.4	-30.4					
720	12	27.5	29.1	29	29.9	-31.1					
780	13	37.5	39.1	90	38.9	-31.8					
840	14	22.5	24.1	16	23.4	-32.5					
900	15	35.5	37.1	72	35.4	-33.1					
960	16	-			-	-33.6					
1020	17	20.5	22.1	13	20.4	-34.2					
1140	19	41.5	43.1	143	41.4	-35.1					
1260	21	20.5	22.1	13	20.4	-36.0					
1380	23	32.5	34.1	51	33.4	-36.8					
1500	25	30.5	32.1	40	31.4	-37.5					
1620	27	25.5	27.1	23	26.4	-38.2					
1740	29	27.5	29.1	29	28.4	-38.8					
1860	31	23.5	25.1	18	24.4	-39.4					
1980	33					-40.0					
2100	35					-40.4					
2220	37					-40.9					
2340	39					-41.4					
2460	41					-41.8					
2580	43					-42.2					
2700	45					-42.6					
2820	47					-43.0					
2940	49					-43.3					
3060	51					-43.7					
3180	53					-44.0					
			(I·T)dB	I·T				(I) dBA	I	(TIF)dB	TIF
PWR SUM		59.2	60.8	1101	67.3		50.4	12.0	4.0	48.8	275
NMS		60.0	61.6	1202	67.9		50.9	12.5	4.2	49.1	285

		Height of Power Line Above Probe Wire or Coil								
		20'	25'	30'	35'	40'	45'	50'	55'	60'
Height Correction Factor dB	100' Probe Wire	0.5	1.1	1.6	2.1	2.5	2.9	3.3	3.6	3.9
	Exploring Coil	19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

FIGURE 6
EXAMPLE-INITIAL MEASUREMENTS-EARTH RETURN CURRENT

3.5.1 In the example the distance between the lower conductor of the power system and the probe wire is 31 feet which is entered at (1). Looking at the table of height correction factors for a 100 foot probe wire at the bottom of the form a correction factor of 1.6 dB is found for a 30 feet height which is entered at (2). While a more precise correction factor (1.72 dB) can be found in Table VI of TE&CM Section 452 the resulting deviation is small and has no significant effect on the final values obtained. When the correction factors are obtained from Table VI it is necessary to change the sign before using them in the form for power system current wave form analysis.

3.5.2 Measurements are completed with C-MSG, FLAT and 20/f weighting and the results recorded in columns (3), (6), and (8) respectively at the listed frequencies. NMS mode overall readings are also made and recorded. It is not necessary to record readings at the higher harmonic frequencies when it is obvious they are at a low level and would have no bearing on the overall telephone circuit noise.

3.5.3 After the measurements have been completed and recorded the calculations described in Paragraphs 3.2, 3.3, and 3.4 are completed and the results entered on the form. Total data is now available for analysis.

4. ANALYSIS

4.1 The recorded results of measurements in the NMS mode in column (10) of Figure 6 shows an overall earth return current of 4.2 amperes. This indicates there is little likelihood of a fundamental frequency problem (excessive longitudinal 60 Hertz voltage in the telephone system). Generally when the overall earth return current approaches or exceeds 20 amperes there is a possibility of a fundamental frequency voltage problem. The I·T (TIF weighted amperes) value in column (5) is 1202 indicating that there is a possibility that the earth return current of one or more harmonic frequencies may be high enough to induce noise in a well balanced telephone circuit.

4.1.1 It is difficult to establish a precise I·T value which will indicate a noise problem will exist. The overall I·T provides a broad indication of the interference potential of a power line. Normally the I·T is not measured unless a noise problem exists and the telephone company has eliminated all potential problem areas in its system. There are situations as discussed in Paragraph 1.1 where these measurements might be completed before a problem is known to exist. As a general rule when the I·T exceeds 1000 a harmonic analysis of the earth return current should be made.

4.1.2 Study of the recorded I·T values for each harmonic frequency in column (5) reveals that all are acceptable except the 540 Hertz component which is 1012. This indicates there is a potential for telephone system noise at this harmonic frequency. As a general rule if the I·T at any frequency exceeds 500 there is a possibility of a noise problem in parallel telephone circuits. This does not, however, guarantee a noise problem cannot occur when the I·T is less than 500 but that there is a lower probability of one occurring. There are other variable contributing factors such as the length of exposure, separation between the telephone and power lines, etc. (See TE&CM Section 452, Paragraph 5).

4.2 The unweighted harmonic frequency earth return current values in column (10) show there may be significant current at four frequencies. They are 180, 300, 420, and 540 Hertz with currents of 0.7, 0.6, 0.6, and 0.7 amperes, respectively. There is little chance of 180 or 300 Hertz contribution to the noise problem due to the low I·T. There is a possibility that the 420 Hertz component might be contributing to the telephone system noise if there is a long exposure. The 540 Hertz component appears to be the principal contributor in this case. When long exposures are involved a 540 Hertz earth return current as low as 0.1 ampere should not be regarded as being insignificant. A substantial longitudinal voltage may be induced in a parallel telephone system which should not automatically be considered a power system problem since the I·T would only 132. (See TE&CM Section 452, Paragraph 5).

4.3 Comparison of the numerical TIF values from column (12) to those from Table III of TE&CM Section 452 shows a good correlation:

Frequency	Column (12)	Table III
180 Hertz	30	30
300 Hertz	224	225
360 Hertz	376	400
420 Hertz	631	650
480 Hertz	966	950
540 Hertz	1365	1320

4.4 The differences between numerical TIF and Table III values are to be expected as are those between the results of overall NMS measurements and power summations. They occur because it is not possible to complete all of the measurements at precisely the same instant in time. During the time period required for completion of the series of measurements there will be power system load variations that will produce these minor variations. When there is a large difference there is a likelihood an error has occurred and a second measurement should be made.

4.5 The 540 Hertz component will be the predominant harmonic in the majority of noise investigations. Power line resonance is often a factor which can be further aggravated by capacitor bank installations. In the example (Figure 6) a capacitor bank located on the field side of the measurement location is assumed. Study of the recorded data would justify a suspicion that there is a power line resonance that is being aggravated by the capacitor.

4.6 Additional measurements of the harmonic frequency earth return currents are completed at other locations to confirm the tentative diagnosis. It will be assumed that the recorded results of a measurements at a location on the field side of the capacitor bank shows an FT of 442 at 540 Hertz with an earth return current of 0.3 ampere. While this is still marginally high it does appear to confirm that the capacitor bank is a major contributor to the noise problem.

4.7 Enough information has now been accumulated to determine that a condition in the power line operation is apparently the principal contributor to the telephone system noise. Even more important the information is in units (I·T and I) which are familiar to a power company engineer and assist him in making decisions regarding possible actions for relieving the problem. Even though a telephone engineer or technician may make some reasonable assumptions relative to the noise contribution from various power system components final determinations should be left to the power company. It is at this point in a noise investigation that the power company should be contacted.

4.7.1 All of the power system current wave form data is presented to the power company. Additional information is also provided showing work which has been performed by the telephone company to determine that telephone shields are continuous and adequately grounded and that telephone circuits have excellent balance. The power company representatives may agree after looking at the data with the tentative diagnosis that there appears to be a capacitor related problem or they may indicate a desire to perform tests themselves. A possible course of action is to negotiate the temporary removal of the ground connection to the capacitor bank during which period additional measurements are made. For the purposes of the example it will be assumed the ground connection has been removed temporarily.

4.7.2 Probe wire measurements as described in Paragraph 3.5 are made at the same location as those shown in Figure 6. Results of these measurements are recorded in the form for power system current wave form analysis as shown in Figure 7. The I·T at 540 Hertz has been reduced from 1012 to 23. The calculated earth return current is about 0.017 ampere. The FT at 420 Hertz has been reduced from 359 to 320 and the earth return from 0.6 to 0.5 ampere. This clearly indicates the capacitor bank is a significant factor in the noise problem.

POWER SYSTEM CURRENT WAVE FORM ANALYSIS

Central Office ALPHA

Power Company BETA ELECTRIC Sheet No. 2

Primary Voltage 7.62 kV 3-Phase Date 6/2/75

Test Location Adjacent to Pedestal A1-5 A1 Route Time 10:30 am

Test Condition Clear and Hot Tester Doc

☒ 100 foot probe wire ☐ Exploring coil type:

Power Line Height (Average) 31 Feet (1); Correction Factor 1.6 dB (2)

FREQ. Hz.	Harmonic	TIF Weighted (Weighing Switch in C-MSG.)			Unweighted (Weighing Switch in 50 KHZ-FLAT or 20/F)					TIF Contribution	
		Reading dB (3)	(2)+(3) $I_f \cdot W_f$ dBA (4)	$I_f \cdot W_f$ wtd. amps (5)	Flat Reading dB (6)	20/f Factor (7)	(6)+(7) or 20f Reading (8)	(8)+(2) -40 dB =(If) dBA (9)	I_f amps (10)	(3)-(8) +40 dB =(T_f) dB (11)	T_f (12)
60	1	-			58.5	-9.5	49.0	10.6	3.4		
120	2	-			28.5	-15.6	12.9	-25.5	0.1		
180	3	20.5	22.1	13	49.0	-19.1	29.9	-8.5	0.4	30.6	34
240	4	-			17.5	-21.6	-4.1	-			
300	5	41.5	43.1	143	59.0	-23.5	35.5	-2.9	0.7	46.0	200
360	6	18.5	20.1	10	31.5	-25.1	6.4				
420	7	48.5	50.1	320	59.5	-26.4	33.1	-5.3	0.5	55.4	589
480	8	20.5	22.1	13	28.5	-27.6	1.0				
540	9	25.5	27.1	23	31.5	-28.6	3.0				
600	10	15.0	16.6	7	19.5	-29.5					
660	11	36.5	38.1	80	39.0	-30.4					
720	12	19.2	20.8	11	17.5	-31.1					
780	13	38.8	40.4	105	38.5	-31.8					
840	14	-			-	-32.5					
900	15	34.0	35.6	60	34.5	-33.1					
960	16	-			-	-33.6					
1020	17	41.5	43.1	143	41.5	-34.2					
1140	19	40.5	42.1	127	40.5	-35.1					
1260	21	37.5	39.1	90	38.0	-36.0					
1380	23	36.5	38.1	80	37.0	-36.8					
1500	25	28.8	30.4	33	29.5	-37.5					
1620	27	20.5	22.1	13	21.5	-38.2					
1740	29	30.3	31.9	39	31.3	-38.8					
1860	31	23.5	25.1	18	24.7	-39.4					
1980	33					-40.0					
2100	35					-40.4					
2220	37					-40.9					
2340	39					-41.4					
2460	41					-41.8					
2580	43					-42.2					
2700	45					-42.6					
2820	47					-43.0					
2940	49					-43.3					
3060	51					-43.7					
3180	53					-44.0					
			(I·T)dB	I·T				(I) dBA	I	(TIF)dB	TIF
PWR SUM		51.4	53.0	446	64.0		48.3	10.9	3.5	42.1	127
NMS		50.9	52.5	422	62.9		48.6	10.2	3.2	42.3	130

		Height of Power Line Above Probe Wire or Coil								
		20'	25'	30'	35'	40'	45'	50'	55'	60'
Height Correction Factor dB	100' Probe Wire	0.5	1.1	1.6	2.1	2.5	2.9	3.3	3.6	3.9
	Exploring Coil	19.5	21.5	23.0	24.4	25.5	26.6	27.5	28.3	29.1

FIGURE 7
EXAMPLE-SECOND MEASUREMENT-EARTH RETURN CURRENT

4.7.3 The next action is to negotiate with the power company to determine if the capacitor bank can be relocated to a point nearer to or at the power substation to reduce the length of exposure. Such action would provide a final solution for the problem.

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